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Evaluation of the Problem Posed by In-Place Pollutants in Baltimore Harbor and Recommendation of Corrective Action - Appendices

Trident Engineering Associates, Inc, Annapolis, Md.

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16. ABSTRACT

This report and a companion report, EPA 440/5-77-015b, present the results of a study of the in-place pollutants in Baltimore harbor and their effect on water quality. This part of the report contains the appendices.

17. KEY WORDS AND DOCUMENT ANALYSIS

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United States
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Office of Water Planning and Standards
Washington, D.C. 20460

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APPENDIX A

THE BALTIMORE HARBOR ENVIRONMENT

A. 1 STREAMFLOW INTO BALTIMORE HARBOR

Baltimore Harbor is located on the Patapsco River upstream from where it joins the Chesapeake Bay. Fresh water enters the Harbor by way of land runoff into storm sewers and by stream drainage to the Harbor.

The U. S. Geological Survey measures (1975) continuously various stream flows which enter Baltimore Harbor. The major points of gauging streamflow are listed below:

Station No.	Station Name	Drainage Area (sq. mi.)	Discharge (ft^3/sec.)		
			Average	Maximum	Minimum
15860	North Branch Patapsco River at Cedarhurst, Md.	56.6	63.4	27,800	3.1
15875	South Branch Patapsco River at Henryton, Md.	64.6	71.6	26,900	0.4
15890	Patapsco River at Hollofield, Md.	285	*	80,600	9.6
15893	Gwynns Falls at Villa Nova, Md.	32.5	36.2	16,200	1.7

* Flow regulated by Liberty Reservoir 11 miles upstream beginning July 22, 1954.

As can be seen from the table above, the average fresh water flow into the Harbor is relatively low compared with the volume of the Harbor of 15 billion cubic feet.

A.2 METEOROLOGY

A.2.1 Winds

The winds in the Baltimore Harbor area blow predominantly from a westerly direction. Table A-1 is a chart of the frequency of occurrence of surface winds at Baltimore-Washington International Airport, about 10 miles from the Harbor. The chart shows that the wind will have a velocity of four miles per hour or more about 93 percent of the time. Of this percent, winds will be from a westerly direction 48 percent of the time, and from an easterly direction about 30 percent of the time. Three percent of the time the wind will have a velocity of 25 miles per hour or greater, and be from a westerly direction.

A.2.2 Hurricanes

Most hurricanes that have affected the eastern coast of the United States have formed either near the Cape Verde Islands or in the western Caribbean Sea. The tracks of tropical hurricanes are extremely irregular. Hurricanes that affect the Baltimore metropolitan area most severely usually arrive from the south-southwest after recurving east of Florida and skirting the coastline. The hurricane season is from July through October.

Table A-1 Percent of Occurrence of Designated Velocities and Directions of Surface Winds at Friendship Airport

	Speed							
Direction	Calm	1 - 3 MPH	4 - 12 MPH	13 - 24 MPH	25 - 31 MPH	32 - 46 MPH	47 & over MPH	Total 4 & over MPH
N		.3	4.4	1.3	.1			5.8
NNE		.3	3.1	.9				4.0
NE		.4	4.1	1.0				5.1
ENE		.2	3.3	1.0				4.3
E		.4	4.7	.9				5.6
ESE		.2	2.3	.4				2.7
SE		.3	2.8	.7				3.5
SSE		.2	2.6	1.4	.1			4.1
S		.5	6.5	2.8	.1			9.4
SSW		.3	3.3	1.3	.1			4.7
SW		.4	5.2	1.6	.1			6.9
WSW		.2	3.3	1.1	.1			4.5
W		.4	5.9	2.9	.3	.1		9.2
WNW		.2	3.3	3.5	.8	.3		7.9
NW		.3	4.4	4.1	.7	.2		9.4
NNW		.2	3.4	2.2	.2			5.8
Totals	2.3	4.8	62.6	27.1	2.6	.6		92.9

The frictional effects of the land surfaces between the Baltimore Harbor area and the Atlantic Ocean decrease the intensity of hurricanes which move into the area. The greatest damage is produced along waterfronts and shores by the high tides and waves and the flooding due to heavy rainfall. Records indicate that the most violent hurricane ever to have struck the North Atlantic Coast of the United States was the one which occurred during September 1944. This hurricane is referred to as the "Great Atlantic Hurricane", the "1944 Cape Hatteras Hurricane", or the "14 September 1944 Hurricane". The storm center passed about 40 miles seaward of the coast of Maryland and did not inflict severe damage in the Baltimore area.

Records for the Baltimore area for the period 1667-1958 show that twenty damaging storms that narrowly missed the Baltimore area have occurred. These storms include both hurricanes and tropical disturbances of large proportions. Dates of the more severe of these storms are as follows:

June 12, 1858
July 24, 1868
October 1877
August 20, 1879
August 23, 1933
October 15, 1954 ("Hazel")
August 12-13, 1955 ("Connie")
August 16-18, 1955 ("Diane")
June 21-23, 1972 ("Agnes")

The most severe storm on record in the Baltimore area was the storm of August 23, 1933. This hurricane moved from a sea path to the coast at a latitude higher than most tropical storms and entered Chesapeake Bay directly from the ocean. Accordingly, there was no attenuation by passing overland. Wind velocities reached 60 miles per hour, and water levels rose to a record height of 8.33 feet above mean low water at Fort McHenry. Damage from tidal flooding in the Baltimore area was estimated to be about $5 million (in 1933 dollars).

Other hurricanes of note include "Hazel", "Connie", and "Agnes". Hurricane "Hazel" struck Baltimore in October 1954, with wind velocities of 45 miles per hour, and river and bay levels reached a stage of six feet above mean low water. This storm was tracked some 60 miles west of Chesapeake Bay. Damage would have been more severe had the storm been farther eastward. The storm of August 12, 1955 ("Connie") caused river and bay levels to rise about seven feet above mean low water. Hurricane "Agnes", June 5, 1972, caused river and bay levels to rise to 3.8 feet above mean low water.

A. 3 OCEANOGRAPHY OF BALTIMORE HARBOR

A. 3. 1 Water Movement

A study of Baltimore Harbor was made in the period 1958 through 1960 by the Johns Hopkins University for the State of Maryland (Stroup, Pritchard, and Carpenter, 1961). The principal objective of this study was to determine the mechanisms which bring about flushing of the Harbor and the rate at which this flushing occurs.

Based upon this intensive three-year study, the following conclusions were reached:

"1. The physical circulation pattern in the Harbor and the chemical properties of the Harbor waters are primarily related to phenomena occurring in the adjacent Chesapeake Bay; they are not in any measurable manner affected by the relatively small inflow of the Patapsco River.

"2. The primary factor contributing to the renewal of water in Baltimore Harbor is a density-induced, three-layered flow pattern. This type of circulation has not previously been described for estuarine embayments.

"The vertically averaged salinity (and density) is essentially constant from the mouth to the head of the Harbor. However there is less vertical variation in salinity (and hence, density) within the Harbor than there is in the adjacent Chesapeake Bay. Therefore, the surface waters of the Harbor are more saline (and hence, denser) than the surface waters in the Bay just outside the Harbor. Likewise, the deep waters in the Harbor are less saline (and hence, less dense) than water at the corresponding depth in the adjacent Bay. As a consequence, both surface and bottom layers exhibit a net inflow to the Harbor, while the water at middepth flows out of the Harbor into the open Bay.

"3. The evidence for this type of circulation pattern is strongest after a period of high discharge from the Susquehanna River, when the vertical salinity gradients are large, and weakest after a period of low flow when the vertical salinity gradients are small. There is some indication that the strength of this circulation is greatest in the winter and early spring months, and least in the summer and fall months.

"4. The average fractional-renewal rate for the main Harbor during the study period was 12% per day, with individual values ranging between 6% and 20%. These values are remarkably high in comparison with previous estimates, which had not taken the three-layered circulation into account. The renewal rate does not appear to depend to any significant degree upon tidal flushing or upon wind-induced motion.

"5. Comparison of acid-waste concentration, determined from the observed-alkalinity anomaly, with the observed pH indicates that there is little or no exchange with the atmosphere of the excess CO_2 produced during acidification of the Harbor waters. Therefore, the full potential buffer capacity of the Harbor waters is not realized, and lowered pH values are accompanied by increased CO_2 tension."

Sediments, both suspended and bottom, may be moved by tidal currents. Tidal current observations in Chesapeake Bay, as recorded in the files of the Coast and Geodetic Survey began in the year 1845. The Coast and Geodetic Survey published the only comprehensive study of the tides and currents in the Bay available (Haight, 1930). This study was based upon all records accumulated to that date.

A survey of tidal currents conducted between 1960 and 1965 by the Coast and Geodetic Survey gives some values for the near bottom currents. The maximum observed velocities and their true directions near the bottom and surface in the proximity of the five recommended soil disposal sites are shown in Table 2-2 (State of Maryland, 1970).

TABLE A-2

Maximum Observed Bottom and Surface Currents in Vicinity of Five Recommended Sites

Site	C&GS Station No.	Maximum Observed Bottom Current			Maximum Observed Surface Current		
		Depth (feet)	Velocity (knots)	True Direction	Depth (feet)	Velocity (knots)	True Direction
Hart-Miller	63	16	0.7	017	8.0	1.1	227
Hart-Miller	82	18	0.65	032	5.0	0.77	230
Black Marsh	60	7	0.5	036*	7.0	0.5	036*
6-7-9 Foot Knolls	52	30	1.3	337	6.0	1.1	347*
6-7-9 Foot Knolls	59	14	0.5	009*	7.0	0.7	322*
Belvidere Shoal	51	32	1.5	352	6.0	1.1	182
Patapsco River	54	29	0.7	297	6.0	0.4	290*
Patapsco River	55	24	0.4	182*	5.0	0.4	347

* Approximate direction only as variations occur frequently. All directions in degrees azimuth with respect to geographical North.

A. 3. 2 Bathymetry

Baltimore Harbor is a relatively shallow draft harbor with a mean depth of slightly less than 16 feet (Quirk, et al, 1973). Exclusive of the shipping channels, which have been dredged to 42 feet deep after dredging, the deepest part of the Harbor is a 40-foot area lying north of Hawkins Point. This is of only limited extent and may be due to dredging at a ship's turning basin north of Hawkins Point.

Only a relatively small area of the Harbor has depths in the range of 30 to 40 feet. The major part of the Harbor in the vicinity of the shipping channels is between 15 feet to 25 feet in depth. Along the shores of the Harbor, and in the Middle Branch, the depth is less than 15 feet. Considerable shoaling exists in these areas. A sizeable portion of these areas have depths that are less than five feet. Where the Patapsco River broadens into the Harbor, and where Gwynn Falls enters the Harbor, shoaling has resulted from the deposition of river-borne sediments. In the past, spoil dredged from the shipping channels was disposed of within the Harbor itself. These areas are indicated on Coast and Geodetic Survey nautical charts. While this practice has been all but discontinued, the shoal areas remain and are labeled "Discontinued Spoil Areas" on Harbor charts.

APPENDIX B

FIELD DATA

B.1 LOCATION OF CORE SITES

Baltimore Harbor is depicted in Figure B-1 relative to the adjoining land areas, the City of Baltimore, the Chesapeake Bay, and shipping channels. Figure B-2 depicts the locations of sampling sites where core borings and grab samples were obtained. Baltimore Harbor proper is divided into several segments, each named as follows: Inner Harbor, Northwest Harbor, and Middle Branch, which are all directly south of Baltimore City proper.

The main section of the Harbor is named the Patapsco River with the Outer Harbor extending from the southern end of the Patapsco River area out into the Chesapeake Bay. As different maps and charts from various sources define these Harbor areas in slightly different locations, we have followed the map and Harbor section names as outlined in EPA's Region III Technical Report #59, dated January 1974 and titled, "Distribution of Metals in Baltimore Harbor Sediments."

In order to measure the amounts of heavy metals and other pollutants present in Baltimore Harbor sediments, twenty sites were chosen for sampling and chemical analyses. The sampling sites were chosen so as to correlate to the main channels and to locations where previous work

BALTIMORE HARBOR
AND
VICINITY

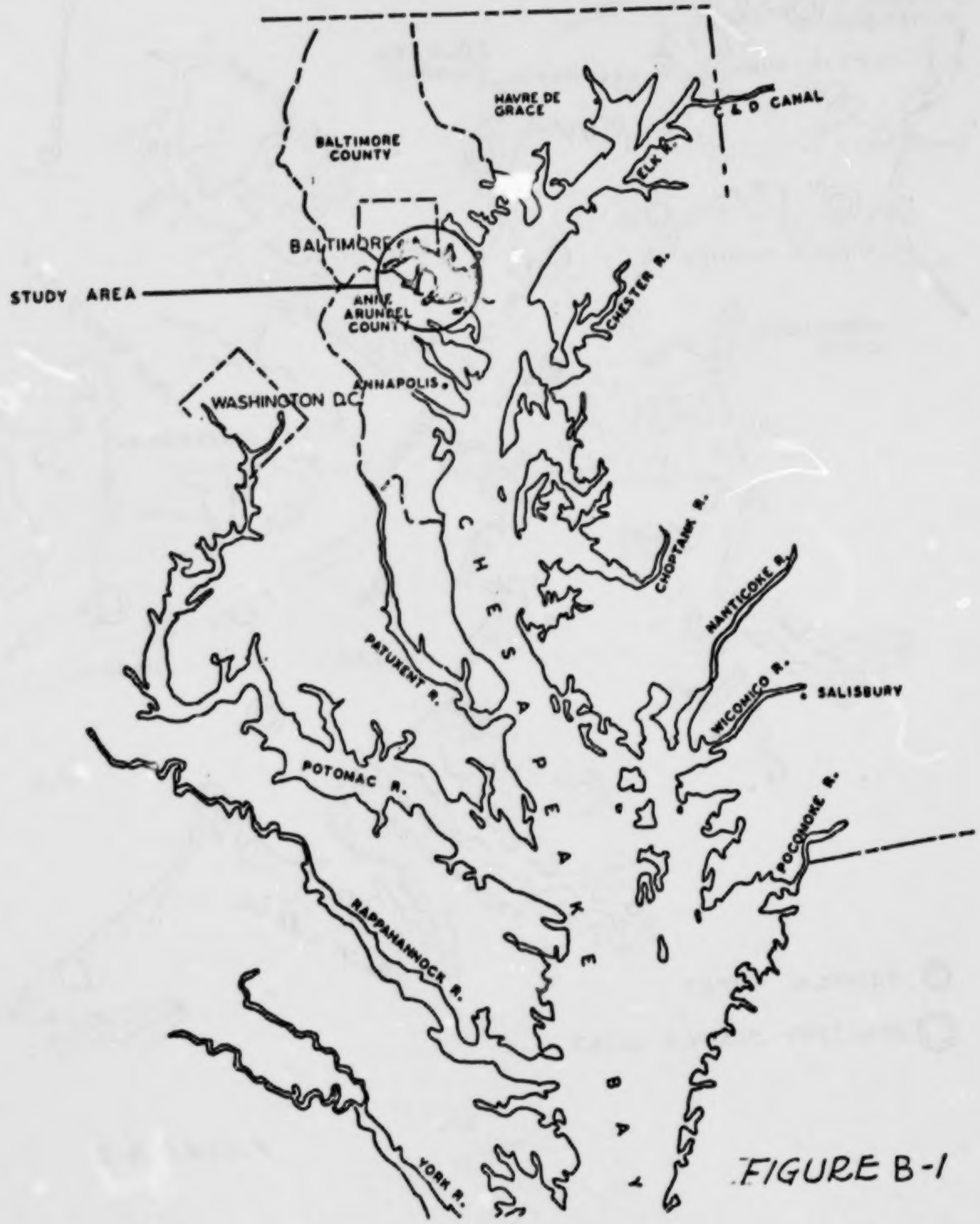

HAVRE DE GRACE
C & D CANAL
BALTIMORE COUNTY
ELK R.
BALTIMORE
STUDY AREA
ANNE ARUNDEL COUNTY
CHESTER R.
ANNAPOLIS
WASHINGTON D.C.
CHESAPEAKE BAY
CHOPTANK R.
NANTICOKE R.
PATUXENT R.
WICOMICO R.
SALISBURY
POTOMAC R.
POCOMOKE R.
RAPPAHANNOCK R.
YORK R.

FIGURE B-1

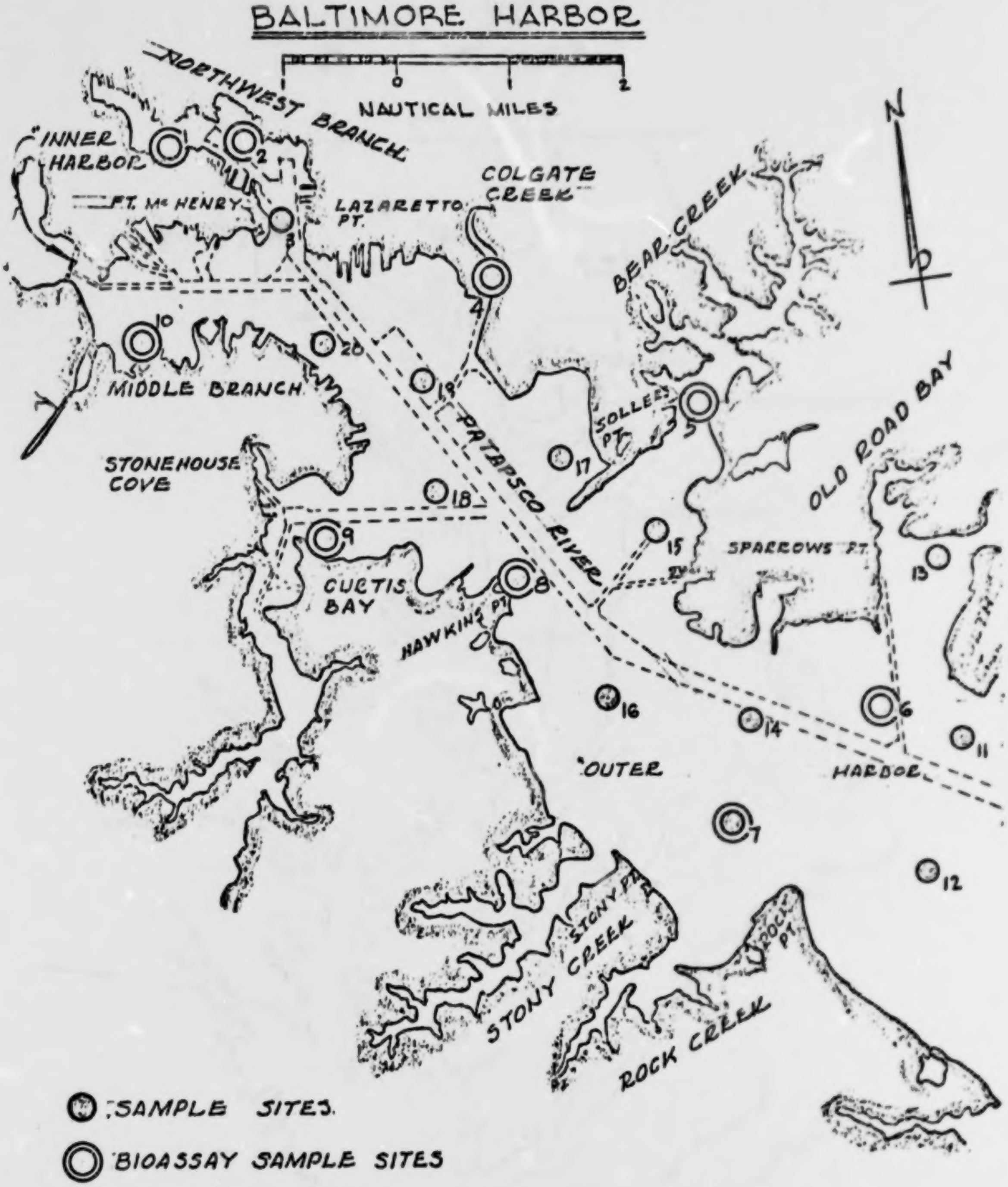

BALTIMORE HARBOR
1
0
1
2
NAUTICAL MILES
N
NORTHWEST BRANCH
INNER HARBOR
FT. McHENRY
LAZARETTO PT.
COLGATE CREEK
BEAR CREEK
OLD ROAD BAY
SOLLERS PT.
MIDDLE BRANCH
STONEHOUSE COVE
PATAPSCO RIVER
SPARROWS PT.
CURTIS BAY
HAWKINS PT.
OUTER
HARBOR
STONY PT.
STONY CREEK
ROCK PT.
ROCK CREEK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
SAMPLE SITES.
BIOASSAY SAMPLE SITES

FIGURE B-2

had been performed. The sites sampled in this study cover the same areas as those used in the January 1974 EPA study. The same heavy metals analyzed in the 1974 EPA study were analyzed in this study. Arsenic and hexane extract were also analyzed.

B.2 FIELD DATA

Table B-1 provides the latitudes and longitudes of the sampling sites used in this study, along with the water depth information recorded by the motor vessel AQUARIUS.

Table B-2 provides salinity and temperature data obtained during sampling operations. These data are recorded in a format to show the salinities in parts per thousand and the temperatures, in degrees Celsius, at the surface and at the bottom at each site.

Table B-3 provides a general verbal description of the appearance and color of the materials obtained while sampling at the indicated sites.

TABLE B-1

GEOGRAPHICAL POSITIONS AND RECORDED DEPTHS OF WATER AT SAMPLING SITES

9 June 1976	Position		Water Depth
Site 1	39° 16' 31" 76° 35' 51"		20'
Site 2	39° 16' 43" 76° 34' 59"		15'
Site 4	39° 15' 21" 76° 32' 10"		22'
Site 5	39° 14' 21" 76° 29' 43"		15'
Site 6	39° 11' 41" 76° 27' 37"		17'
Site 7	39° 10' 36" 76° 29' 21"		20'
Site 8	39° 12' 39" 76° 31' 40"		20'
Site 9	39° 13' 06" 76° 36' 04"		20'
10 June 1976			
Site 6	39° 11' 41" 76° 27' 37"		17'
Site 11	39° 11' 22" 76° 27' 00"	Hard Sand	15'
Site 12	39° 10' 14" 76° 27' 14"		17'

Continued ...

TABLE B-1 (Continued)

	Position		Water Depth
Site 11	39° 11' 22" 76° 27' 00"	Hard sand and shell	17'
Site 13	39° 12' 56" 76° 27' 01"		8'
11 June 1976			
Site 7	39° 10' 37" 76° 29' 30"		19'
Site 14	39° 11' 25" 76° 29' 05"		19'
Site 15	39° 13' 15" 76° 30' 09"		16'
Site 16	39° 11' 39" 76° 30' 48"		15'
Site 1	39° 16' 31" 76° 35' 51"		19'
12 June 1976			
Site 2	39° 16' 33" 76° 34' 58"		14'
Site 3	39° 15' 56.5" 76° 34' 21"		33'
14 June 1976			
Site 4	39° 15' 22" 76° 32' 10"		24'
Site 5	39° 14' 21" 76° 29' 43"		15'

Continued . . .

TABLE B-1 (Continued)

	Position	Water Depth
Site 8	39° 12' 38" 76° 31' 40"	19'
Site 17	39° 13' 57.5" 76° 31' 33"	17'
Site 9	39° 13' 06" 76° 34' 02.5"	18'
15 June 1976 Site 10	39° 14' 51" 76° 36' 03"	15'
Site 18	39° 13' 27" 76° 32' 41"	21'
Site 19	39° 14' 26" 76° 32' 54.5"	36'
Site 20	39° 14' 55" 76° 34' 08"	22'

TABLE B-2

Salinity (S) - Temperature (T) Data

Site surface - bottom -	S ppt	T °c
(1)	5.44 5.22	25.00 24.66
(2)	5.33(5.36) 6.21(5.42)	25.05(23.95) 24.17(22.63)
(3)	5.30 8.05	24.72 19.92
(4)	5.65(4.60) 5.87(7.78)	23.68(25.80) 23.67(20.78)
(5)	4.68(3.22) 5.90(4.20)	23.93(28.22) 23.30(26.71)
(6)	2.92 5.37	24.50 21.83
(7)	4.16(3.63) 5.26(5.85)	26.07(24.61) 23.18(23.67)
(8)	4.22(5.90) 5.03(5.91)	26.58(24.02) 26.07(23.52)
(9)	5.02(5.62) 5.72(5.63)	25.15(24.50) 22.06(25.70)
(10)	3.83(5.28) 5.12(5.72)	27.39(23.77) 21.87(23.72)
(11)	2.83 5.63	25.53 24.65
(12)	3.02 7.70	25.66 21.00
(13)	3.50 3.62	28.20 28.70
(14)	3.70 7.78	25.05 21.78

Continued ...

TABLE B-2 (Continued)

(15)	3.60 5.68	26.59 27.50
(16)	4.54 5.84	26.88 28.33
(17)	5.54 5.64	24.00 23.64
(18)	5.88 5.88	23.82 23.44
(19)	5.57 6.92	24.17 23.56
(20)	5.54 5.76	26.10 26.38

Notes on S-T Data

1. Numbers in ( ) are data taken at or near the same site 1 - 3 days later.
2. Data taken at the same site before coring and then after coring (about 1 hour) agree within ± .02 S units.

TABLE B-3

FIELD DESCRIPTION OF CORE SAMPLES (ss)

(2 cores per station)

(1) 8-9 ft of core oil-grease appearance (black)-bottom 4 feet is tan sand (lower interstitial H_2O sample was black)

(2) 9.5-10 ft Black mud-similar to #1 - some sand (interstitial mud smells strongly asphaltic)

(3) 11.5-12 ft Black oily-asphaltic to about 10 ft - last 1.5 ft is tan sandy clay

(4) 7-9 ft Black asphaltic clay to about 6 ft grading into sandy clay containing shell debris

(5) 11-11.5 ft 1.5 ft of black asphaltic mud - rest of core is sandy clay with shell fragments

(6) 10.75 ft top 3 ft is black asphaltic mud. The rest is grey mud

(7) 6 ft gray-tan silty mud with high water content-the top two ft. contains shell fragments.

(8) 11 ft of Black asphaltic clay - bottom ft is sandy day core cutting head is covered with red pigment (Fe_2O_3?)

(9) 11-13 ft top ft. contains a yellow-green greasy substance-rest is black mud grading into sandy clay near the bottom 2 ft

(10) 6.5-8 ft Black asphaltic mud - lower 1/3 of core is sandy, black mud

(11) 1.5 ft gray mud with shell fragments (initial cores were hard packed sand that broke the core liners)

(12) 10-13 ft of black clay

(13) 6-10 ft of black mud -last ft is grey sand (shallow water 5-8 ft so core could not penetrate)

(14) 10 ft of gray sandy clay grading to lt. brown

(15) 10 ft black asphaltic mud - last 3 ft is sandy mud

(16) 10 ft top two ft is black clay - the rest is tan sandy clay

Continued ...

TABLE B-3 (Continued)

(17) 9-11 ft top 5 ft is asphaltic black mud - next 4-6 ft is sandy clay - pebbles at 9 ft

(18) 9-11 ft top 3 ft is black mud - the rest is grey clay

(19) 8 ft top 4 ft is black and oily-bottom 4 ft is gray clay

(20) 8-11 ft black mud grading to gray mud in the last 4 ft

APPENDIX C

GEOCHEMICAL ANALYSES

C. 1 SAMPLE PREPARATION

Filtered Water Samples

A composite water sample of the water column at each site was collected with polyethylene tubing and buckets. The water was pumped up in three fractions (lower 1/3, middle 1/3, and upper 1/3) by a completely plastic submersible pump. The water was mixed and this composite used directly for the elutriate test. A portion of this water was filtered through a 0.45 µm filter (Millipore), acidified with Ultrex HNO_3 and refrigerated at or near 4°C for analyses as the filtered water sample.

Interstitial Water Samples

The interstitial water sample was collected by removing, with plastic spoons, two portions of each core (5-10 and 40-45 cm depth), quickly placing each sample in a Reeburgh-type sediment squeezer (Bricker, 1975). The entire operation is done under a nitrogen gas atmosphere. Fifty to 60 mls of water is extracted and then acidified with Ultrex HNO_3, and refrigerated at 4°C. Detailed operation of this equipment can be found in Bricker (1975). The interstitial water passes through a 0.22 µm filter and so represents dissolved metals.

Sediment Analysis

The sediments were collected with a 15-ft. piston corer with a polycarbonate core liner. The samples for the bioassay were collected with a Ponar type grab sampler. Sediment samples were removed and kept from contact with metals. Metal and hexane samples were immediately placed in polyethylene bags and refrigerated above freezing (near 4°C). Samples for PCB analyses were placed in clean glass bottles topped with acetone washed aluminum foil and then capped. Separate samples were also prepared for sediment size and B.E.T. analyses.

Elutriate Test

Unfiltered water from the composite batch was mixed with fresh sediment in a 4:1 ratio by volume, sealed and shaken for 30 minutes by a mechanical shaker. The mixture was then centrifuged at 10,000 rpm for 5 minutes, and the entire sample filtered through a 0.45 µm filter. The water was then acidified with Ultrex HNO_3 and refrigerated at 4°C. The entire process normally took from 1 - 3 hours per sample.

C.2 ANALYTICAL METHODS

Oil and Grease

Samples of waters were extracted in a separatory funnel with hexane. Sediment samples were extracted in a soxhlet extractor. Quality control was maintained by spiking selected samples with a high boiling point lab oil. Completed details of these methods is in Standard Methods (APHA 1976).

Arsenic

Samples of waters containing nitric acid were boiled down with sulfuric acid to remove nitrates. Sediments were digested with a mixture of sulfuric and nitric acids followed by boiling off the nitric acid. Arsenic was determined by UV-Vis Spectrophotometer using Standard Methods (APHA 1976; US-EPA 1974). Quality control was maintained by spiking selected samples with sodium arsenate. The UV-Vis Spectrophotometer used was the Spectronic 20.

Metals (other than arsenic)

Water samples were obtained with nitric acid present and were analyzed as nitrates. The sediment samples were digested with reagent quality HNO_3 - water mixture 1:1 ratio. Two grams of dried sediments to 20 mls.

of solution was heated to near dryness. This procedure was repeated three times. The decanted liquid was then analyzed for the metals.

AA Flame Methods

All sediments and most water samples were analyzed using a Perkin-Elmer Model #117 Atomic Absorption Spectrophotometer. Where sufficient volume of water samples was available, water samples were boiled down to concentrate metals. Quality control was maintained by spiking selected sampled with the metal to be analyzed.

AA Flameless Methods

Water analyzed by flameless methods were all eluted waters or interstitial waters. The instruments used were the Perkin-Elmer Model #503 AA Spectrophotometer, the HGA-2100 Graphite Furnace, and the Perkin-Elmer Background Corrector. Quality control was maintained by analyses of spiked samples and by analyses of standards containing 0.0%, 0.1%, 0.3%, 0.5%, 0.7%, and 1.0% NaCl. There proved to be no salt background which could not be removed by normal operation of the charring cycle up to about 0.7% to 1.0% NaCl (salinity of 7 to 10). All NaCl used was either reagent grade or Baker "ULTREX" purity depending on the content of the metal in the reagent salt.

Even "ULTREX" NaCl contained sufficient nickel to interfere and a minimum detectable limit of 5 ppb was the best that could be obtained for nickel. All standards used to calibrate the instrument and water used to zero it contained 0.5% NaCl and 1% HNO_3. The best analytical line for chromium is outside usable spectrum of the deuterium background lamp and, therefore, no background correction was used for chromium. The high charring temperature proved sufficient to avoid any background problems as evidenced by the lack of any smoke peaks during the atomization cycle of the instrument (a chart recorder was employed). Zinc was analyzed by flameless methods in the 56 samples submitted to the Devon lab only where zinc was less than 25 ppb. Normal flame AA methods were used for higher concentrations of zinc.

Mercury

The standard cold vapor technique was used for mercury using the Perkin-Elmer Model 117 AA and the Perkin-Elmer mercury system. Quality control was maintained by spiking selected samples with mercury standard.

C.3 ANALYTICAL PROCEDURES, DISCUSSION, AND RESULTS

Elutriate Test

The elutriate test (Lee and Plumb, 1974) developed by the Army Corps of Engineers, is probably the single most pertinent test available to test for metal release as a result of dredging operations. This test attempts to determine the amount of toxic metals released into the water column from (or removed from the water column by) the sediment. The procedure is to shake a fixed volume of sediment with four times the volume of harbor water and then filter and analyze the elutrient. Modifications were required in order to process the samples during the ship time available to us. Rather than shake for 30 minutes and then filter, the sample was centrifuged for five minutes after being shaken. This modification was required because of the inordinate length of time involved in filtering a thick suspension through a 0.45 µm filter. As this procedure decreases the sediment water exchange period slightly (straight filtering, without centrifugation, would be longer because of filter clogging), it might lead to less exchange of metals. Bricker (1975) suggests that times related to the settling time of dredged materials be used (4 - 6 hours in this area, Ibid.) for the elutriate test.

As the most accessible (to the water column) metal-rich portion of the sediment is the interstitial water, one might expect the elutriate test to reflect the interstitial water composition. In fact, the elutriate test in most cases shows less of the metal than is found in the interstitial water. This very important result puts a serious restraint on the use of the elutriate test in anoxic bottom sediments such as much of Baltimore Harbor.

Tables C-2 - C-21 show the metal concentrations in the elutriate samples taken from each available core interval (0.16, 0.5, 1.0, 2.0, 3.0, 5.0, 7.0, 10.0, 15.0 ft. The Army Corps of Engineers suggests that concentration of each dissolved metal not exceed 1.5 times its original concentration in the filtered water column (Bricker, 1975). Where the metal concentration is higher in the elutriate as compared to the reference water, metals are presumed to be released from the sediment. Where the metal level is lower in the reference water, the metal is presumed to have been removed by the sediment.

Because of the limited nature of this study, many elements could not be analyzed by the most sensitive available technique, i.e., flameless atomic absorption spectrometry. The result is that some elements will show concentrations below detection limits. This will not always allow for direct comparison between elutriate and filtered overlying water.

Interstitial Water

Analyses of interstitial water was deemed vital because it may be the major source of the releasable metals during dredging and because no data exists of metals for these fluids in Baltimore Harbor. Interstitial water data is very dependent on the manner in which the sample is collected (Bricker, 1975; Sommer and Diachenko, 1974); great care must be demonstrated in preventing oxidation of anoxic sediments, as iron may precipitate and scavenge or adsorb trace metals out of solution.

The samples are collected and quickly (in a matter of a few minutes at most) placed in a nitrogen gas squeezer apparatus which is completely enclosed within a nitrogen atmosphere. The collected liquid is audified, refrigerated, and stored for analysis. Interstitial water was squeezed from two portions of each core, at 5 - 10 cm and at 40 - 45 cm. Bricker found maximum concentrations of metals at 5 - 10 cm depth, and relatively constant concentrations below 50 cm depth.

The data in Tables C-2 - C-21 indicate that maximum concentrations are very often found at the lowest core interval, probably indicating a gradient increasing with depth. Pb appears to be at high levels at sites 6, 12, 2, and 7; Cd at sites 9, 16, 19, and 20; Cu at sites 6 and 7; Cr at sites 2, 5, and 12; Ni at site 9; Zn at sites 2, 6, 7, 10, 14, and 16; Mn at sites 3, 7, and 12; Hg at sites 2, 6, 16; and As at sites 3, 18, 19, and 20. The sites with the highest levels appear to lie on the western side of the Harbor with Pb and Cu highest near the Bay mouth; Ni, Cd, and As highest in the center; Cr high at the head and mouth of the Harbor, and Mn, Zn, and Hg dispersed throughout the area. An important point to note is that interstitial water samples often have higher concentrations of metals than elutriate samples from the same site. The high levels are much higher than can be accounted for by dilution during the elutriate test (4:1). If one further takes into account the fact that many of these metals are thought to be released from the sediment during the elutriate procedure, the high interstitial (or low elutriate) values may be indicative of oxidation and precipitation during the elutriate analysis, with subsequent loss of dissolved metals for analyses. This interpretation would indicate the elutriate test, for anoxic sediments, would tend to underestimate the concentrations of those elements that tend to be scavenged or precipitated with hydrous iron oxides.

Sediment Analyses

Sediment samples were collected by coring with a 15-foot piston corer. Sediment samples were retained in a polycarbonate core liner. All samples for metal analyses were protected from metal contamination by preventative handling or by removing, by hand, any portion of the sample that came into contact with metal portions of gear. Samples used for hexane extraction and especially for PCB analysis were treated so as not to incur any organic contamination. The samples were refrigerated at approximately 4°C until analysis. Eight sediment intervals were delineated for sampling from 0.16 to 10.0± 2 ft (corrected core depths utilizing Piggot's (1941) correction factors, due to compaction). All sample collection, processing, and refrigeration took place within 30 minutes of collection -- usually in less time.

The data for the nine metals, As, Hg, Cd, Cr, Cu, Mn, Ni, Pb, Zn, hexane extractable hydrocartons, and moisture content are illustrated in Tables C-22 through C-41.

There is no doubt that metal levels at most sites and at most depths are polluted by EPA (1973) standards. The only element for which standards exist (Cd, Pb, Hg, and Zn) that is not routinely above polluted levels is

Hg. The technique used to extract metals is slightly more vigorous than that used by Villa and Johnson (1974) so that higher metal values for the same site may be expected.

Grain Size and Surface Area Analyses

Dried sediment samples were processed for grain size by an automated grain size apparatus called a Sedigraph. This device measures the sedimentation rates of particles in suspension and presents these data as a cumulative percent distribution in terms of Stokes or equivalent spherical diameter. The range of size determined was from 100 μm to 0.1 μm. Accuracy is believed to be better than 1% with reproducibility of about 0.5%. It should be noted that size and surface area data for these sediments do not represent those characteristics as found in the natural state as they have been dried prior to measurement. However, the data should be internally consistent and thus comparable within this set of data. The top and bottom of all cores were analyzed.

The grain size distribution, Table C-1, as indicated by average particle size varies from a high of 22.5 μm (7-6) to a low of 1.8 μm (9-8). The general size range is in the clay range with a few in the silt class. The specific surface area (meters ^{2}/grain) varies from a high 62.6 (9-1) to a very low 0.7 (10-7) with most values falling in the 20 range.

C-4 SUMMARY

Reference to Tables C-2 to C-41 indicates that Cd is highest in Colgate Creek and Bear Creek (Sites 4 and 5) with moderate levels in the Inner Harbor area (Site 2). Cr is particularly high at the Inner Harbor (Sites 1, 2, and 3), Colgate Creek (Site 4), Bear Creek (Site 5), Sparrows Point (Site 15), at scattered sites, e.g., 6, 17, 18, and 20. Cu is very high in the Inner Harbor (Sites 1, 2, and 3) and at Colgate Creek (Site 4). Pb shows high values in the Inner Harbor (Sites 2 and 3), Colgate Creek (Site 4), Bear Creek (Site 5), Curtis Bay (Site 9), and near Old Road Bay (Site 13). Mn is high throughout the Harbor; except for the inner portion, it is particularly high at surface or depth at the following sites; 5, 6, 7, 8, 12, 13, 14, 16, 17, 18, and 19.

Hg shows elevated levels in the Inner Harbor (Sites 1, 2, 3), Colgate Creek (Site 4), and Curtis Bay (Site 9). Mi is high in the Inner Harbor (Site 2 and 3), Curtis Bay (Site 4), and Site 19. Ni is relatively constant at 75 - 100 ppm through much of the Harbor. Zn is high everywhere, but highest of all in the Inner Harbor, Colgate and Bear Creeks, Old Road Bay, Curtis Bay, and Sparrows Point area. The metals discussed above were selected because they are the metals determined by Villa and Johnson (1974). In almost every case (the only exceptions are Hg levels at a few sites), the high and low sediment levels agree within the limits of coverage. This is remarkable considering that three years passed between sampling, during which dredging, storms and traffic have left their imprint. It probably indicates that the degree of industrial output is sufficient to replace quickly, any removed or transferred metal concentrations. In addition to the metals listed above, As was found to be very highly concentrated in the Inner Harbor (Sites 2 and 3), Colgate Creek (Site 4), the Curtis Bay - Hawkins Point area (Sites 8 and 9), as well as the Middle Harbor area.

It is worth noting that many of the metals show marked decreases in concentration at particular core intervals or sediment depths. At Site 1, most elements remain constant until level 6-7, and then decrease rapidly. This corresponds to about 5 - 7 feet. Moisture and hexane levels also decrease at level 7. Sites 2, 8, 14, 16, 17, and 19 show a marked decrease in metals and hydrocarbons at or near layer 6 (5+ft). Site 15 and 18 show the marked decrease between layers 6 and 7 (3 - 5 ft). Sites 9 and 20 show the decrease at or near layer 7-8 (7 - 10 ft). Sites 3, 10, 11, and 12 show no change or have very low concentrations. Sites 5, 6, and 13 show decreases near layers 3-5 with 13 showing a very strong change at layer 4. In general, there appears to be a major decrease in most metals, hydrocarbons, and moisture content at about 5 ft ± 2 ft, everywhere in the Harbor.

The majority of chemical analyses for metals were conducted by flame atomic absorption analyses, a standard technique for these substances. The relatively low cost and high sensitivity of this technique allowed for the analyses of a large number of both sediment and water samples. A selected number of water samples were analyzed by a more sensitive analytical technique, that of flameless atomic absorption analysis. The higher cost of this technique dictated that only a limited number of samples could be analyzed by this method. This approach results in the analyses of a maximum of samples, while still allowing for a small number of samples to be analyzed at very low concentration levels. Direct comparison between the water samples analyzed at low detection levels (flameless) and sediment/water samples analyzed by the conventional flame technique is not possible as one set of data is below the detection limits of the other for those samples containing concentrations at or near the detection limits of the conventional technique. While this presents data that are difficult to compare on an individual basis, a total analysis is possible when viewing all samples together as contained in the tables for the sediment and water-metal concentrations.

TABLE C-1

Particle Size Analysis and Surface Area Analysis

Sample Identification Site # - Depth*	Average Particle Size (E.S.D., microns)	Specific Surface Area (m^2/g)
1-1	9.2	11.7
2-1	14.0	15.7
3-1	8.0	18.1
4-1	12.5	13.5
5-1	9.0	24.3
6-1	2.4	28.1
7-1	2.5	47.3
8-1	7.8	60.0
9-1	4.6	62.6
10-1	8.0	9.5
11-1	3.3	11.4
12-1	2.5	28.3
13-1	8.0	20.6
14-1	2.3	28.0
15-1	7.6	21.2
16-1	6.8	43.4
17-1	2.8	28.3
18-1	2.7	53.4
19-1	2.8	33.4
20-1	3.7	18.5
1-7	6.0	10.4
2-7	4.8	16.9
4-7	5.0	15.2
5-7	2.4	19.2
7-6	22.5	0.7
10-7	3.6	19.2
19-7	2.0	22.5
3-8	3.2	16.0
6-8	2.0	25.6
8-8	3.2	17.4
9-8	1.8	27.7
12-8	2.1	25.0
13-8	8.0	11.0
14-8	1.95	25.7
15-8	2.8	17.9
16-8	2.6	17.6
17-8	2.0	22.9
17-8-2	2.1	25.0
18-8	2.1	26.1
20-8	2.8	18.8

* 1 = 0.16 feet
7 = 7.0 feet
8 = 10.0 feet

TABLE C-2

Trident No.	Sample Type	Metals µg/1								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
1	filtered H_2O	< 8	<0.2	8	19	14	380	43	< 50	20
1 (5-10 cm.)	interstitial H_2O	34	1	< 2	99	< 2	1,840	< 5	68	610
1 (40-45 cm.)	interstitial H_2O	<100	2	< 2	273	16	1,670	< 5	107	1,500
1-1	elutriate	< 25	< 1	< 2	14	10	420	< 5	8	24
1-2	elutriate	< 25	< 1	< 2	16	14	740	< 5	3	20
1-3	elutriate	< 25	< 1	< 2	16	16	340	< 5	5	10
1-4	elutriate	< 25	< 1	< 2	18	12	480	< 5	5	21
1-5	elutriate	< 25	< 1	< 2	15	23	660	< 5	4	35
1-6	elutriate	< 25	< 1	< 2	15	10	340	< 5	5	3
1-7	elutriate	< 25	< 1	< 2	13	6	240	< 5	36	4

< Less than detection limits

TABLE C-3

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
2	filtered H_2O	< 8	< 0.2	8	17	13	320	36	<50	19
2 (5-10 cm.)	interstitial H_2O	< 50	3	< 25	100	50	1,900	<75	570	1,100
2 (40-45 cm.)	interstitial H_2O	< 50	6	< 25	88	< 50	1,500	< 75	< 290	2,500
2-1	elutriate	< 25	< 1	< 25	< 38	< 50	330	< 75	< 290	31
2-2	elutriate	< 25	< 1	< 25	< 38	< 50	210	125	< 290	38
2-3	elutriate	55	< 1	< 25	< 38	< 50	170	< 75	< 290	44
2-4	elutriate	33	< 1	< 25	< 38	< 50	190	< 75	< 290	31
2-5	elutriate	< 25	< 1	< 25	< 38	< 50	320	< 75	< 290	19
2-6	elutriate	< 25	< 1	< 25	< 38	< 50	330	< 75	< 290	31
2-7	elutriate	< 25	< 1	< 25	< 38	< 50	310	< 75	< 290	25

< Less than detection limits

TABLE C-4

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
3	filtered H_2O	< 8	<0.2	10	< 5	17	450	50	< 50	24
3 (5-10 cm.)	interstitial H_2O	74	2	< 25	50	< 50	2,700	< 75	< 290	350
3 (40-45 cm.)	interstitial H_2O	67	2	< 25	38	< 50	2,700	100	< 290	390
3-1	elutriate	< 25	< 1	< 25	< 38	< 50	310	< 75	< 290	25
3-2	elutriate	< 25	< 1	< 25	< 38	< 50	190	< 75	< 290	25
3-2	elutriate	44	< 1	< 25	< 38	< 50	470	< 75	< 290	19
3-3	elutriate	< 25	< 1	25	< 38	< 50	330	< 75	< 290	19
3-4	elutriate	38	< 1	31	< 38	< 50	200	< 75	< 290	19
3-5	elutriate	< 25	< 1	< 25	< 38	< 50	280	< 75	< 290	25
3-6	elutriate	< 25	< 1	< 25	< 38	< 50	330	< 75	< 290	25
3-7	elutriate	< 25	< 1	< 25	< 38	< 50	530	75	< 290	31

< less than detection limits

TABLE C-5

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
4	filtered H_2O	< 8	<0.2	8	<5	14	410	36	< 50	39
4 (5-10 cm.)	interstitial H_2O	41	<1	< 2	103	12	750	5	55	180
4 (40-45 cm.)	interstitial H_2O	140	<1	< 2	90	< 2	1,490	< 5	26	150
4-1	elutriate	< 25	<1	< 2	14	10	460	< 5	8	30
4-2	elutriate	<25	<1	< 2	14	22	690	< 5	5	35
4-3	elutriate	<25	< 1	< 2	17	26	580	< 5	6	29
4-4	elutriate	31	<1	< 2	17	12	400	< 5	7	35
4-5	elutriate	45	<1	< 2	14	11	130	<5	9	35
4-6	elutriate	< 25	< 1	< 2	15	8	< 50	<5	4	47
4-7	elutriate	28	< 1	< 2	18	5	220	<5	6	47

< less than detection limits

TABLE C-6

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
5	filtered H_2O	< 8	< 0.2	7	< 5	12	420	47	< 50	73
5 (5-10 cm.)	interstitial H_2O	< 25	< 1	< 2	466	< 2	310	< 5	73	120
5 (40-45 cm.)	interstitial H_2O	< 25	< 1	< 2	46	10	< 50	< 5	240	53
5-1	elutriate	< 25	< 1	< 2	15	14	80	10	8	35
5-2	elutriate	< 25	< 1	< 2	12	12	320	< 5	4	82
5-3	elutriate	< 25	< 1	< 2	10	7	220	< 5	4	35
5-4	elutriate	< 25	< 1	< 2	18	5	740	< 5	16	25
5-5	elutriate	< 25	< 1	< 2	18	30	820	< 5	27	76
5-6	elutriate	< 25	< 1	< 2	16	13	< 50	< 5	< 5	22
5-7	elutriate	< 25	< 1	< 2	16	18	900	< 5	11	25

< **less than detection limits**

TABLE C-7

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
6	filtered H_2O	<8	<0.2	7	< 5	14	270	43	< 50	78
6 (5-10 cm.)	interstitial H_2O	<100	11	< 25	< 38	< 50	1,000	100	2,200	2,700
6 (40-45 cm.)	interstitial H_2O	<100	6	25	< 38	750	12,300	< 75	2,900	5,000
6-1	elutriate	<25	<1	25	< 38	< 50	350	< 75	< 290	86
6-2	elutriate	<25	<1	< 25	< 38	< 50	340	< 75	< 290	77
6-3	elutriate	32	<1	< 25	< 38	< 50	950	< 75	< 290	191
6-4	elutriate	<25	<1	< 25	< 38	< 50	1,100	< 75	< 290	56
6-5	elutriate	<25	<1	< 25	< 38	< 50	980	< 75	< 290	77
6-6	elutriate	<25	<1	< 25	< 38	< 50	660	< 75	< 290	63
6-7	elutriate	<25	<1	< 25	< 38	< 50	550	< 75	< 290	65
6-8	elutriate	<25	<1	<25	< 38	< 50	1,700	150	< 290	130
6-1 (A)	elutriate	<25	1	<25	< 38	< 50	340	< 75	< 290	77

< less than detection limits

TABLE C-8

Trident No.	Sample Type	Metals µg/1								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
7	filtered H_2O	< 8	<0.2	9	< 5	15	410	36	< 50	32
7 (5-10 cm.)	interstitial H_2O	<100	6	<25	38	50	980	<75	360	1,000
7 (40-45 cm.)	interstitial H_2O	<100	6	*	< 38	*	3,700	<75	< 290	*
7-2	elutriate	< 25	1	<25	< 38	< 50	450	<75	< 290	44
7-3	elutriate	< 25	1	<25	< 38	< 50	1,200	<75	< 290	31
7-4	elutriate	37	< 1	<25	< 38	< 50	1,100	<75	< 290	56
7-5	elutriate	28	< 1	<25	< 38	< 50	1,200	<75	< 290	44
7-6	elutriate	< 25	< 1	<25	< 38	< 50	1,200	<75	< 290	100

< less than detection limits   * ran out of sample

TABLE C-9

Trident No.	Sample Type	Metals µg/1								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
8	filtered H_2O	< 8	< 0.2	9	< 5	12	450	36	< 50	31
8 (5-10 cm.)	interstitial H_2O	64	<1	< 2	29	7	970	< 5	508	250
8 (40-45 cm.)	interstitial H_2O	240	<1	< 2	43	< 2	1,580	< 5	399	170
8-1	elutriate	< 25	<1	< 2	16	2	260	< 5	5	24
8-2	elutriate	< 25	<1	< 2	14	< 2	740	< 5	5	20
8-3	elutriate	< 25	<1	< 2	15	< 2	640	< 5	9	47
8-4	elutriate	< 25	<1	< 2	17	< 2	<50	< 5	5	24
8-5	elutriate	< 25	<1	< 2	13	< 2	820	< 5	< 5	41
8-6	elutriate	< 25	<1	< 2	15	3	560	< 5	8	35
8-7	elutriate	< 25	<1	< 2	14	6	530	< 5	5	65
8-8	elutriate	< 25	<1	< 2	14	7	80	< 5	13	53

< less than detection limits

TABLE C-10

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
9	filtered H_2O	<8	< 0.2	9	17	11	390	85	< 50	31
9 (5-10 cm.)	interstitial H_2O	55	< 1	22	57	<17	190	910	< 170	160
9 (40-45 cm.)	interstitial H_2O	57	1	21	61	<17	250	920	< 170	70
9-1	elutriate	<50	1	15	< 20	13	63	260	< 100	23
9-2	elutriate	<50	2	13	< 20	13	63	190	< 100	26
9-3	elutriate	<25	<1	25	< 38	<50	36	< 75	< 290	25
9-4	elutriate	<25	<1	< 25	< 38	<50	64	< 75	< 290	56
9-5	elutriate	<25	<1	< 25	< 38	<50	64	< 75	< 290	50
9-6	elutriate	<25	<1	< 25	< 38	<50	71	125	< 290	77
9-7	elutriate	50	<1	< 25	< 38	<50	28	< 75	< 290	19
9-8	elutriate	<50	1	12	34	<10	330	130	< 100	15

< less than detection limits

TABLE C-11

Trident No.	Sample Type	Metals µg/1								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
10	filtered H_2O	<8	<0.2	9	<5	14	360	36	<50	24
10 (5-10 cm.)	interstitial H_2O	53	<1	<2	47	4	1,670	< 5	284	950
10 (40-45 cm.)	interstitial H_2O	64	< [illegible]	<2	42	10	2,000	< 5	102	210
10-1	elutriate	< 25	<1	<2	14	<2	110	< 5	<5	29
10-2	elutriate	< 25	<1	<2	14	<2	270	< 5	18	82
10-3	elutriate	< 25	<1	<2	15	4	< 50	< 5	5	35
10-4	elutriate	< 25	<1	<2	16	<2	< 50	< 5	6	76
10-5	elutriate	44	<1	<2	17	12	160	< 5	16	47
10-6	elutriate	< 25	<1	<2	15	2	500	< 5	5	59
10-7	elutriate	< 25	<1	<2	15	<2	< 50	< 5	4	47

< less than detection limits

TABLE C-12

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
11	filtered H_2O	< 8	<0.2	6	38	19	330	94	< 50	84
11 (5-10 cm.)	interstitial H_2O	<50	3	< 25	< 100	84	4,400	1,450	< 500	370
11 (40-45 cm.)	interstitial H_2O	<50	2	< 25	< 100	<50	1,600	1,550	< 500	150
11-1	elutriate	<50	< 1	10	57	17	790	240	<100	70
11-2	elutriate	39	< 1	< 25	< 38	<50	500	< 75	<290	83
11-3	elutriate	58	1	10	41	17	400	230	<100	81

< less than detection limits

TABLE C-13

Trident No.	Sample Type	Metals µg/1								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
12	filtered H_2O	< 8	< 0.2	7	< 5	12	300	29	< 50	32
12 (5-10 cm.)	interstitial H_2O	< 100	2	< 2	80	35	1,860	< 5	1,400	550
12 (40-45 cm.)	interstitial H_2O	< 100	2	< 2	39	19	2,370	70	1,900	320
12-1	elutriate	< 25	< 1	< 2	14	18	570	< 5	10	5
12-2	elutriate	< 25	< 1	< 2	14	7	460	< 5	5	24
12-3	elutriate	< 25	< 1	< 2	14	35	600	< 5	5	24
12-4	elutriate	< 25	< 1	< 2	14	31	280	< 5	11	29
12-5	elutriate	< 25	< 1	< 2	16	23	1,460	< 5	13	82
12-6	elutriate	< 25	< 1	< 2	14	5	830	< 5	8	29
12-7	elutriate	< 25	< 1	< 2	15	11	310	< 5	5	53
12-8	elutriate	< 25	< 1	< 2	14	18	850	< 5	5	47

< less than detection limits

TABLE C-14

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
13	filtered H_2O	<8	<0.2	6	< 5	12	90	32	<50	15
13 (5-10 cm.)	interstitial H_2O	<50	2	<25	<38	<50	510	<75	<290	260
13 (40-45 cm.)	interstitial H_2O	<50	4	<25	<38	<50	1,200	<75	<290	350
13-1	elutriate	30	< 1	<25	<38	<50	210	<75	<290	44
13-2	elutriate	<25	< 1	<25	<38	<50	250	<75	<290	63
13-3	elutriate	<25	< 1	<25	<38	<50	240	100	<290	100
13-4	elutriate	<25	1	<25	<38	50	36	<75	<290	31
13-5	elutriate	<25	< 1	<25	<38	<50	420	100	<290	83
13-6	elutriate	<25	< 1	<25	<38	<50	100	<75	<290	71
13-7	elutriate	<25	< 1	<25	<38	<50	160	<75	<290	77
13-8	elutriate	<25	< 1	<25	<38	<50	230	<75	<290	77

< less than detection limits

TABLE C-15

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
14	filtered H_2O	< 8	< 0.2	8	< 5	15	380	36	< 50	22
14 (5-10 cm.)	interstitial H_2O	< 50	3	< 25	< 38	< 50	480	< 75	1,100	530
14 (40-45 cm.)	interstitial H_2O	< 50	3	< 25	< 38	< 50	290	< 75	< 290	1,200
14-1	elutriate	< 25	< 1	< 25	< 38	< 50	260	< 75	< 290	25
14-2	elutriate	< 25	< 1	< 25	< 38	< 50	190	< 75	< 290	19
14-3	elutriate	< 25	< 1	< 25	< 38	< 50	260	< 75	< 290	25
14-4	elutriate	< 25	< 1	< 25	< 38	< 50	200	< 75	< 290	25
14-5	elutriate	< 25	< 1	< 25	< 38	< 50	71	100	< 290	31
14-6	elutriate	< 25	< 1	< 25	< 38	< 50	820	< 75	< 290	38
14-7	elutriate	< 25	< 1	< 25	< 38	< 50	1,300	75	< 290	25
14-8	elutriate	32	< 1	< 25	< 38	50	1,300	< 75	< 290	25

< less than detection limits

TABLE C-16

Trident No.	Sample Type	Metals μg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
15	filtered H_2O	< 8	< 0.2	8	< 5	15	380	36	<50	48
15 (5-10 cm.)	interstitial H_2O	< 50	3	< 25	38	<50	390	175	360	270
15 (40-45 cm.)	interstitial H_2O	< 50	3	< 25	<38	<50	450	<75	< 290	240
15-1	elutriate	< 25	< 1	< 25	<38	<50	50	< 75	< 290	31
15-2	elutriate	< 25	< 1	< 25	<38	50	36	75	<290	136
15-3	elutriate	< 25	< 1	< 25	< 38	83	57	75	<290	19
15-4	elutriate	< 25	< 1	< 25	< 38	<50	570	<75	<290	19
15-5	elutriate	< 25	< 1	< 25	< 38	<50	390	< 75	<290	19
15-6	elutriate	< 25	< 1	< 25	< 38	<50	250	< 75	<290	44
15-7	elutriate	< 25	< 1	25	< 38	66	1, 100	< 75	<290	89

< **less than detection limits**

TABLE C-17

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
16	filtered H_2O	<8	<0.2	8	<5	18	450	43	<50	23
16 (5-10 cm.)	interstitial H_2O	<100	5	<25	<38	<50	460	150	800	1,200
16 (40-45 cm.)	interstitial H_2O	<100	16	31	<38	<50	1,600	<75	360	1,000
16-1	elutriate	<25	<1	<25	<38	<50	240	75	<290	56
16-2	elutriate	<25	<1	<25	<38	<50	110	<75	<290	<19
16-3	elutriate	<25	<1	<25	<38	<50	310	<75	<290	<19
16-4	elutriate	<25	<1	<25	<38	<50	270	100	<290	19
16-5	elutriate	<25	<1	25	<38	<50	200	<75	<290	44
16-6	elutriate	<25	<1	<25	<38	<50	490	125	<290	44
16-7	elutriate	<25	<1	25	<38	<50	760	100	<290	25
16-8	elutriate	<25	<1	<25	<38	<50	1,600	<1600	<75	25

< less than detection limits

TABLE C-18

Trident No.	Sample Type	Metals µ.g/1								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
17	filtered H_2O	<8	<0.2	8	<5	16	410	36	<50	26
17 (5-10 cm.)	interstitial H_2O	50	1	<25	<38	<50	1,600	75	640	320
17 (40-45 cm.)	interstitial H_2O	<100	3	<25	<38	<50	430	<75	2,300	780
17-1	elutriate	<25	< 1	<25	<38	<50	110	<75	<290	31
17-2	elutriate	<25	< 1	<25	<38	<50	230	<75	<290	31
17-3	elutriate	<25	< 1	<25	<38	<50	300	75	<290	19
17-4	elutriate	<25	< 1	< 25	<38	50	260	<75	<290	19
17-5	elutriate	<25	< 1	< 25	< 38	< 50	28	< 75	<290	38
17-6	elutriate	<25	< 1	< 25	<38	< 50	680	< 75	< 290	25
17-7	elutriate	<25	< 1	25	<38	<50	1,200	100	< 290	<19
17-8	elutriate	<25	< 1	25	<38	<50	1,700	<75	< 290	<19

< less than detection limits

TABLE C-19

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
18	filtered H_2O	< 8	<0.2	9	< 5	17	420	39	<50	24
18 (5-10 cm.)	interstitial H_2O	< 50	2	< 25	< 38	<50	340	75	<290	180
18 (40-45 cm.)	interstitial H_2O	200	1	< 25	< 38	<50	310	100	<290	180
18-1	elutriate	< 25	< 1	< 25	< 38	< 50	110	< 75	<290	19
18-2	elutriate	< 25	< 1	< 25	< 38	83	64	< 75	<290	25
18-3	elutriate	< 25	< 1	< 25	< 38	< 50	71	<75	<290	25
18-4	elutriate	< 25	< 1	< 25	< 38	<50	78	<75	<290	19
18-5	elutriate	25	< 1	< 25	< 38	<50	260	<75	<290	25
18-6	elutriate	< 25	< 1	< 25	< 38	< 50	1,400	<75	<290	< 19
18-7	elutriate	< 25	< 1	< 25	< 38	50	1,000	100	<290	19
18-8	elutriate	< 25	< 1	< 25	< 38	< 50	1,300	<75	<290	19

< less than detection limits

TABLE C-20

Trident No.	Sample Type	Metals ug/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
19	filtered H_2O	<8	<0.2	10	<5	17	540	50	<50	30
19 (5-10 cm.)	interstitial H_2O	71	2	25	<38	<50	310	<75	290	180
19 (40-45 cm.)	interstitial H_2O	84	3	<25	38	<50	820	<75	<290	180
19-1	elutriate	<25	< 1	< 25	< 38	<50	120	<75	<290	19
19-2	elutriate	<25	< 1	< 25	< 38	<50	130	<75	<290	25
19-3	elutriate	<25	< 1	< 25	< 38	<50	140	75	<290	19
19-4	elutriate	<25	< 1	< 25	< 38	<50	110	<75	<290	25
19-5	elutriate	<25	< 1	31	< 38	<50	64	75	<290	130
19-6	elutriate	<25	< 1	< 25	< 38	<50	750	<75	<290	31
19-7	elutriate	<25	< 1	50	< 38	<50	810	<75	<290	19

< less than detection limits

TABLE C-21

Trident No.	Sample Type	Metals µg/l								
		As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
20	filtered H_2O	< 8	< 0.2	12	< 5	14	450	50	<50	68
20 (5-10 cm.)	interstitial H_2O	71	2	25	< 38	<50	820	<75	290	150
20 (40-45 cm.)	interstitial H_2O	63	2	25	< 38	<50	980	<75	<290	180
20-1	elutriate	<25	< 1	<25	< 38	<50	140	<75	<290	25
20-2	elutriate	<25	< 1	<25	< 38	<50	71	<75	<290	19
20-3	elutriate	<25	< 1	<25	< 38	<50	130	75	<290	< 19
20-4	elutriate	< 25	< 1	< 25	38	<50	130	< 75	<290	< 19
20-5	elutriate	< 25	< 1	< 25	< 38	<50	140	< 75	<290	56
20-6	elutriate	25	< 1	< 25	< 38	<50	570	75	<290	< 19
20-7	elutriate	<25	< 1	< 25	< 38	<50	310	< 75	<290	< 19
20-8	elutriate	<25	< 1	25	< 38	<50	280	< 75	<290	< 19

< less than detection limits

TABLE C-22

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
1-1	sediment	62.48	11,600	53	2.88	7	1,870	570	360	67	190	1,140
1-2	sediment	63.49	17,300	101	5.67	11	3,230	1,120	290	78	280	1,650
1-3	sediment	63.23	12,500	58	4.55	6	1,430	580	310	56	45	930
1-4	sediment	57.45	7,500	51	7.55	7	1,500	440	330	61	170	1,040
1-5	sediment	59.69	8,500	46	4.70	5	1,050	390	360	56	110	580
1-6	sediment	54.91	8,200	81	2.78	3	560	660	340	50	15	350
1-7	sediment	43.70	750	5	0.23	<1	130	23	220	39	26	56

TABLE C-23

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
2-1	sediment	80.50	48,500	110	4.13	23	4,100	2,800	800	160	1,300	2,100
2-2	sediment	72.18	28,600	106	2.61	14	2,500	1,900	450	110	930	1,400
2-3	sediment	62.45	52,900	130	5.73	23	3,600	2,200	240	170	1,200	1,900
2-4	sediment	62.68	59,000	185	3.82	22	3,700	2,400	190	120	1,800	1,700
2-5	sediment	64.25	40,800	95	4.56	11	1,900	1,400	230	75	1,500	1,100
2-6	sediment	56.23	5,900	21	3.35	2	470	320	200	42	430	330
2-7	sediment	60.92	320	10	0.11	< 1	120	31	290	37	13	71

TABLE C-24

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
3-1	sediment	54.83	58,400	104	1.77	5	750	2,900	430	170	640	610
3-2	sediment	59.52	13,600	107	1.34	5	920	1,700	550	100	630	740
3-3	sediment	60.50	17,900	116	1.09	7	1,100	1,800	480	93	690	990
3-4	sediment	62.65	20,200	116	2.60	7	1,200	1,500	380	74	660	980
3-5	sediment	63.46	29,000	142	2.79	11	1,400	1,400	310	69	1,100	1,400
3-6	sediment	65.34	35,700	180	2.85	10	1,800	1,600	340	66	970	1,300
3-7	sediment	60.20	31,700	152	2.98	11	740	1,500	310	71	920	780
3-8	sediment	56.23	24,700	84	4.35	5	700	1,200	360	71	1,600	730

TABLE C-25

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
4-1	sediment	81.73	15,500	77	0.73	30	440	340	270	42	430	830
4-2	sediment	62.01	15,300	96	1.01	92	900	710	380	74	630	1,700
4-3	sediment	68.06	18,000	160	1.60	130	1,100	690	350	75	800	2,000
4-4	sediment	69.15	22,100	290	2.39	270	1,300	910	230	80	1,300	4,000
4-5	sediment	66.65	21,300	850	3.86	340	1,000	750	180	56	1,200	3,300
4-6	sediment	59.25	7,300	117	1.96	77	430	260	740	50	390	1,200
4-7	sediment	46.34	2,500	30	0.28	20	140	61	540	32	460	380

TABLE C-26

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
5-1	sediment	76.64	35,200	103	0.11	59	4,500	540	490	82	770	6,200
5-2	sediment	85.63	46,000	117	0.95	21	1,700	370	370	79	850	3,700
5-3	sediment	71.96	18,000	112	0.62	8	1,200	300	280	84	1,700	3,100
5-4	sediment	61.71	8,400	83	0.33	5	350	180	370	58	620	1,900
5-5	sediment	59.29	1,300	20	0.18	1	170	43	820	44	68	160
5-6	sediment	59.76	530	18	<0.02	<1	130	11	610	42	27	89
5-7	sediment	56.91	400	21	<0.02	<1	95	12	1,100	37	19	86

TABLE C-27

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
6-1	sediment	62.64	4,700	22	0.57	3	220	160	700	82	220	1,300
6-2	sediment	55.11	3,500	38	0.71	2	130	120	720	88	510	1,100
6-3	sediment	54.51	540	21	0.12	1	39	31	1,100	39	24	140
6-4	sediment	59.49	< 100	7	0.05	1	42	13	950	29	15	80
6-5	sediment	61.01	400	11	0.07	1	65	15	1,100	34	15	89
6-6	sediment	54.25	280	8	0.06	<1	55	13	960	30	12	83
6-7	sediment	49.02	350	8	0.07	<1	43	14	960	32	<10	88
6-8	sediment	49.95	340	12	0.06	<1	42	14	790	28	15	85

TABLE C-28

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
7-1	sediment	73.09	2,900	18	0.29	1	550	140	720	69	220	830
7-2	sediment	55.15	1,900	76	0.45	2	320	140	880	100	360	1,300
7-3	sediment	57.32	600	27	0.29	2	69	45	1,100	52	64	230
7-4	sediment	57.18	< 100	18	0.05	1	78	17	1,100	35	<10	100
7-5	sediment	54.28	< 100	14	0.06	1	65	21	960	33	13	88
7-6	sediment	16.28	280	1	0.02	<1	12	2	100	3	<10	15

TABLE C-29

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
8-1	sediment	68.54	13,700	82	0.62	4	670	320	740	56	260	1,430
8-2	sediment	68.90	9,000	122	0.74	3	390	250	750	53	250	1,120
8-3	sediment	66.55	12,100	159	0.78	4	900	330	550	55	480	890
8-4	sediment	70.55	9,400	256	1.30	3	310	310	530	52	210	1,140
8-5	sediment	66.82	6,000	177	1.40	2	200	330	550	64	18	840
8-6	sediment	58.54	3,100	42	1.42	1	110	85	860	50	15	300
8-7	sediment	52.76	2,200	18	0.30	1	41	62	1,790	39	53	100
8-8	sediment	55.69	1,700	21	0.19	1	36	40	1,250	31	<10	140

TABLE C-30

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
9-1	sediment	80.89	4,200	56	0.46	3	300	300	1,710	115	176	630
9-2	sediment	84.26	2,600	72	0.36	4	260	220	2,290	73	<100	710
9-3	sediment	67.33	9,600	76	1.37	3	510	330	720	52	300	750
9-4	sediment	67.12	6,500	74	1.33	2	390	280	540	46	320	500
9-5	sediment	76.15	16,000	131	4.69	4	290	260	210	53	350	440
9-6	sediment	64.54	15,000	125	1.61	2	320	270	220	32	510	420
9-7	sediment	67.04	17,400	1,117	13.08	2	590	580	300	38	1,600	830
9-8	sediment	63.33	3,700	14	0.19	1	82	61	510	66	<30	140

TABLE C-31

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
10-1	sediment	53.43	4,600	31	0.42	3	680	160	380	76	170	390
10-2	sediment	55.32	7,100	49	0.46	4	320	230	280	73	180	650
10-3	sediment	61.74	5,100	45	0.83	5	400	230	290	71	170	710
10-4	sediment	52.34	6,700	37	1.26	4	260	280	280	58	160	480
10-5	sediment	54.30	3,500	77	0.64	3	260	230	230	50	160	350
10-6	sediment	45.87	1,800	37	0.34	1	160	150	350	46	97	180
10-7	sediment	46.36	3,100	93	0.66	1	200	160	370	48	130	220

TABLE C-32

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
11-1	sediment	54.88	400	11	0.06	2	23	23	1,360	50	<20	160
11-2	sediment	48.36	260	10	0.04	2	21	10	690	29	<10	60
11-3	sediment	45.37	<100	5	0.02	1	26	9	680	48	<20	54

TABLE C-33

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
12-1	sediment	62.05	1,200	19	0.20	1	73	57	1,440	49	37	430
12-2	sediment	61.28	<50	19	0.12	1	30	29	1,670	41	<10	300
12-3	sediment	51.05	1,000	17	0.15	1	29	32	1,720	42	<10	270
12-4	sediment	56.40	560	25	0.27	1	30	47	1,360	62	13	330
12-5	sediment	58.98	260	12	0.06	2	29	16	1,100	35	13	96
12-6	sediment	60.79	<50	14	<0.05	1	28	11	1,230	35	<10	85
12-7	sediment	58.75	<50	11	0.05	1	20	8	1,400	30	<10	85
12-8	sediment	59.26	<50	12	<0.05	1	23	9	1,260	33	<10	90

TABLE C-34

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
13-1	sediment	64.41	6,100	33	1.34	8	370	220	1,100	54	1,300	3,400
13-2	sediment	53.98	7,800	33	2.26	9	360	220	1,200	52	1,300	5,500
13-3	sediment	58.88	7,500	39	3.37	10	270	160	1,200	55	990	3,900
13-4	sediment	36.35	<100	9	0.07	<1	32	12	150	16	17	51
13-5	sediment	48.96	180	5	0.05	1	47	12	240	18	<10	64
13-6	sediment	45.39	<100	7	0.04	<1	53	11	190	17	<10	59
13-7	sediment	44.84	<100	7	0.03	<1	47	11	180	18	<10	51
13-8	sediment	36.75	<100	6	0.05	<1	20	9	170	13	<10	44

TABLE C-35

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
14-1	sediment	65.11	2,400	35	0.50	2	300	150	620	50	160	590
14-2	sediment	58.29	3,300	22	0.97	2	120	57	1,500	47	120	320
14-3	sediment	52.67	2,600	25	0.47	2	150	89	1,900	63	130	490
14-4	sediment	66.73	6,000	41	0.75	3	340	190	860	64	290	1,300
14-5	sediment	61.02	4,300	65	0.89	4	200	170	790	58	400	1,100
14-6	sediment	49.13	<100	13	0.06	1	69	16	1,200	35	20	98
14-7	sediment	58.34	280	10	0.61	1	51	16	1,300	31	22	94
14-8	sediment	50.36	180	12	0.05	<1	45	16	1,200	32	17	100

TABLE C-36

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
15-1	sediment	67.72	21,000	48	1.63	15	1,700	500	660	75	500	2,600
15-2	sediment	65.36	26,000	65	1.08	13	1,400	480	630	68	470	2,200
15-3	sediment	58.34	17,000	75	1.11	11	1,100	360	540	54	690	2,100
15-4	sediment	55.56	8,800	51	0.70	8	760	250	640	47	300	1,200
15-5	sediment	51.52	1,800	9	0.43	1	130	38	640	33	52	140
15-6	sediment	53.53	250	8	0.24	2	100	23	550	29	18	110
15-7	sediment	51.30	210	6	0.06	1	48	16	800	30	13	77
15-8	sediment	56.45	670	7	0.40	1	68	26	920	35	30	120

TABLE C-37

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
16-1	sediment	66.59	3,900	48	0.40	3	435	160	870	56	160	870
16-2	sediment	59.43	5,600	27	0.62	1	240	140	1,500	55	190	590
16-3	sediment	58.39	2,200	38	0.52	2	150	130	1,900	68	160	510
16-4	sediment	56.58	1,900	34	0.47	2	210	110	1,800	53	170	500
16-5	sediment	62.46	4,100	93	0.94	4	360	330	590	88	700	1,340
16-6	sediment	62.70	<100	12	0.51	1	57	17	1,500	36	52	100
16-7	sediment	58.62	<100	10	0.53	1	47	17	1,400	36	<10	86
16-8	sediment	57.75	<100	8	0.06	2	55	16	1,700	38	<10	100

TABLE C-38

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
17-1	sediment	61.48	8,300	50	0.75	2	640	270	720	61	240	870
17-2	sediment	57.71	4,300	32	0.44	3	250	130	1,300	54	150	400
17-3	sediment	58.79	1,800	34	0.37	2	170	71	1,200	47	170	350
17-4	sediment	60.14	3,300	45	0.36	2	210	72	1,100	44	140	450
17-5	sediment	74.43	18,600	184	1.36	8	950	400	390	57	610	1,800
17-6	sediment	48.54	1,500	13	0.52	<1	100	44	660	44	81	120
17-7	sediment	54.18	<100	13	0.04	<1	41	17	720	32	22	100
17-8	sediment	54.92	<100	12	0.09	<1	33	25	1,200	54	33	100

TABLE C-39

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
18-1	sediment	65.11	16,100	108	0.84	5	760	410	490	65	300	1,530
18-2	sediment	67.88	13,100	116	1.15	5	720	460	500	61	320	1,740
18-3	sediment	64.91	10,500	103	1.25	4	640	420	490	53	350	1,430
18-4	sediment	66.00	7,400	150	1.66	4	540	450	570	56	400	1,060
18-5	sediment	59.42	2,800	77	1.30	1	220	190	470	61	280	400
18-6	sediment	55.22	390	10	0.09	<1	38	22	1,900	41	29	83
18-7	sediment	58.59	<100	6	0.05	<1	40	19	2,800	43	30	92
18-8	sediment	50.43	1,900	10	0.13	1	130	32	2,300	53	28	100

TABLE C-40

Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
19-1	sediment	61.62	4,500	63	0.73	4	330	260	830	78	220	660
19-2	sediment	58.23	8,000	73	0.81	5	480	390	930	63	280	1,100
19-3	sediment	59.79	7,300	74	0.96	4	370	400	690	76	200	1,050
19-4	sediment	57.50	6,200	101	1.08	4	390	320	790	95	180	1,190
19-5	sediment	62.19	6,400	63	0.96	5	440	350	730	95	300	1,290
19-6	sediment	54.73	820	9	0.36	2	100	48	1,000	42	48	150
19-7	sediment	53.32	3,300	14	0.58	1	160	96	730	45	84	170

TABLE C-41

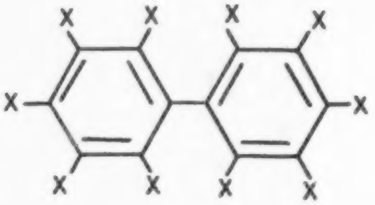
Trident No.	Sample Type	Moisture %	Total Hydro-Carbons Hexane Extract mg/kg	Metals mg/kg								
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
20-1	sediment	62.81	8,900	58	1.21	4	450	390	510	62	290	210
20-2	sediment	61.25	9,700	50	1.04	3	410	290	390	81	210	620
20-3	sediment	66.70	13,400	68	1.34	4	650	460	390	68	230	1,050
20-4	sediment	58.50	17,100	75	1.81	4	610	470	390	71	530	920
20-5	sediment	55.66	12,700	96	2.85	3	340	550	350	70	420	700
20-6	sediment	53.42	10,100	116	1.64	2	250	300	510	63	230	460
20-7	sediment	56.28	1,900	8	0.09	<1	73	55	610	62	48	110
20-8	sediment	50.64	13,800	87	2.16	3	290	750	200	47	310	120

APPENDIX D

POLYCHLORINATED BIPHENYLS

D.1 INTRODUCTION

Polychlorinated biphenyls (PCB's) are aromatic organochlorine compounds obviously named for their chemical structure, consisting of a biphenyl group with ten available sites for chlorination.



PCB

X — Cl

In normal manufacturing, PCB's are not isolated for marketing as single compounds, but rather as a mixture of chlorinated biphenyls. Jensen (1970) states that in theory, 189 different arrangements containing 1 to 8 chlorine atoms are possible, but that in normal manufacturing, 4 to 8 chlorine atoms attach to the parent biphenyl molecule (even with only 4 to 8 chlorine atoms, there are 102 different molecular arrangements). Walker (1976) states that there are 209 isomers in PCB mixtures and formulations.

Since single polychlorinated biphenyls are not isolated for marketing, the degree of chlorination (as percentage by weight of chlorine) identifies the commercial product. In the United States, PCB's are manufactured by Monsanto Chemical Co., St. Louis, Missouri, with production somewhere between 15,900 to 38,600 metric tons per year (Walker, 1976) of Aroclor - the trade name. Eight Aroclor formulations - 1221, 1232, 1242, 1248, 1254, 1260, 1262 and 1268 are marketed. The "12" designation defines the product as a PCB while the last two digits (42, 48, etc.) indicate the percentage by weight of chlorine.

Widespread use of PCB's started before 1930 (Penning, 1930). The primary use of PCB's is in manufacturing electrical transformers and capaciters although they are also used in marine anti-fouling paints, in cardboard cartons, as dust-allayers, in insecticides, as plasticizers, as hydraulic fluids, in protective coatings, as sealers, in inks, waxes and adhesives, in thermostats, as lubricants, as grinding fluids and as sealers in electrical applications.

The use of PCB's in the variety of applications previously mentioned stems partially from their physical and chemical properties. Generally, low vapor pressures, low water solubility, high dielectric constants, inertness, stability at high temperatures, resistance to acids, bases and microbial activity, and fat solubility characterize PCB's. Many of these characteristics, especially fat solubility, inertness, and resistance to microbial activity, make PCB's persistent contaminants in the environment.

Although PCB's are widely used (their early development is documented in Schmidt and Schultz, 1881), concern over their toxicity first appeared in the 1930's when workers making PCB's developed certain pathologies (Jones and Alden, 1936; Good and Pensky, 1943; Drinker et al., 1937; Flinn and Jarvik, 1939; Greenberg et al., 1939; Schwartz, 1943; Schwartz and Barlow, 1942; and Schwartz and Peck, 1943). However, PCB presence in the environment became noticed when many investigators observed a series of unidentified peaks on gas chromatograms (reviewed in Reynolds, 1971). Most of the samples were pesticide residues especially from fish and raptors containing fairly large concentrations of organochlorine pesticides (many pesticides such as DDT, methoxychlor, etc. are quite similar to PCB's in molecular structure). Jensen (1966) was the first to relate the unidentified peaks to PCB's. The problem of PCB interference with pesticide analyses is discussed in Reynolds (1971), Zitko (1972), Stalling and Huckins (1973), and Stalling et al. (1972).

After Jensen's (1966) initial confirmation of PCB's in wildlife, more reports of PCB contamination followed as reviewed in Walsh (1972), Reynolds (1971), Dustman et al. (1971), and Walker (1976). Generally, these reports continued to cover fish and raptors although some attention was beginning to center on other species.

After observing high levels of PCB's in many animals, concern was expressed over the possible toxicity of PCB's especially after McLaughlin et al. (1963) reported that Aroclor 1242 was toxic and teratogenic. Some of these early studies are reviewed in Walsh (1972), Reynolds (1971), and Walker (1976) concerning toxicity and mode of action for PCB's.

Walker (1976) points out that high concentrations of PCB's occur concomitently with heavy industrial activity. In this study, an analysis is made of sediments from Baltimore Harbor for the presence of two PCB's - Aroclor 1248 and Aroclor 1260.

D.2 PROCEDURES

A total of 20 stations (Fig. D-1) within Baltimore Harbor were sampled by a piston corer equipped with a 4.6 m polycarbonate liner. Two cores were taken per station. Completion of coring took 6 days during 9 June to 15 June 1976.

Samples for PCB analyses were taken from the cores at four depths - 5 cm, 15 cm, 30 cm and 61 cm. Core material was removed with wooden applicator sticks and immediately transferred to clean glass vials. Vials were sealed by first capping with aluminum foil (acetone-washed) and then capping with plastic lids.

All samples were shipped to Analytical Bio Chemistry Laboratories, Inc., Columbia, Mo. for PCB analyses. A weighed portion of the air dried sample was adjusted to approximately 20% moisture. Each sample was extracted with methanol/chloroform (1:1) by blending in a Sorval Omni mixer. Following filtration, the extract was diluted with water and the PCB's partitioned into the chloroform. A series of repeated extractions and backwashings removed the methanol from the chloroform phase. The chloroform was evaporated and the residue subjected to Florisil column chromatography (20 g, 22 mm i.d.) in which the PCB's were eluted with 200 ml of hexane. The eluant was evaporated and transferred to a final volume of 5 ml. Microliter injections into a gas-liquid chromatograph equipped with Ni_{63} electron capture detectors were used for identification and quantification.

The GLC-EC parameters were: injector temperature - 225 C; column - 1.83 cm x 4 mm, 2% OV-210, 1.5% OV-17 on Chrom W 100/120, temperature 205 C; and detector temperature - 300 C. Calculations were based on the middle five peaks of Aroclor 1248 and the last nine peaks of Aroclor 1260 and reported as ppm (w/w) air dried basis. A peak ratio judgement was made to determine the species or peaks to be considered for identification and quantification.

A total of 80 samples were analyzed for Aroclor 1260 and 76 for Aroclor 1248. A 5 cm sample was not run for station 7 (Fig. D-1). Duplicates were run on station 8 - 5 cm depth.

Statistical procedures were from Sokal and Rohlf (1969). Calculations were performed on a Canon F-20P statistical calculator.

Figure D-1 - Sampling (coring) stations for PCB analyses within Baltimore Harbor

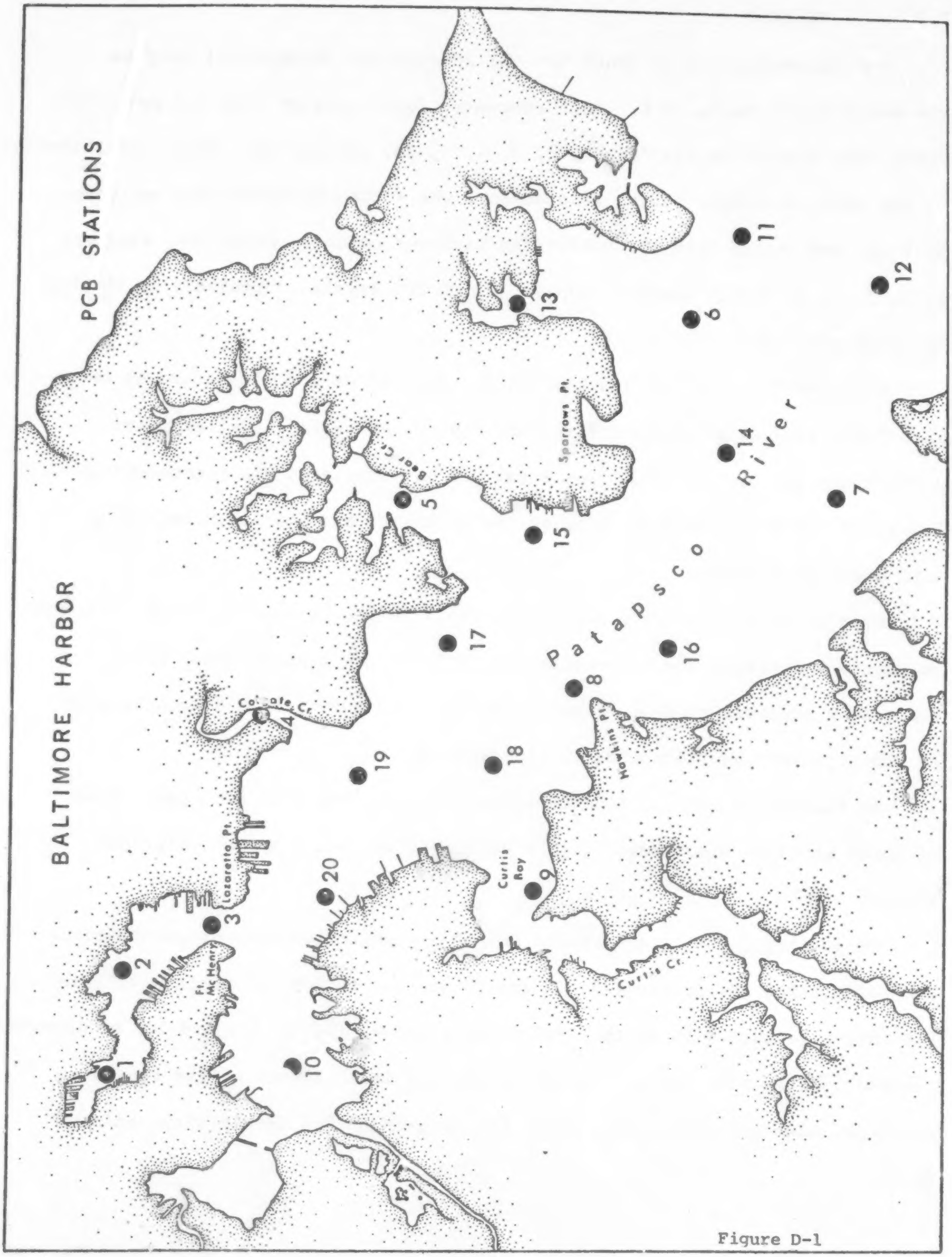

BALTIMORE HARBOR
PCB STATIONS
Patapsco River
Bear Cr.
Sparrows Pt.
Colgate Cr.
Lazaretto Pt.
Ft. McHenry
Curtis Bay
Curtis Cr.
Hawkins Pt.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Figure D-1

D.3 RESULTS

PCB concentrations by depth for the 20 stations (Figure D-1) samples are presented in Table D-1. High concentrations, greater than 1.0 ppm total PCB's, are present at stations 1, 2, 3, 4, 5, 10, 15, and 18. Gross contamination of the upper sediments occurs at station 1 where PCB concentrations approach 84.2 ppm and remain high throughout the sediment column. Generally, stations 1, 2, 3, 4, 5, and 15 contain extremely high PCB levels, especially in the top 30 cm of the core.

Stations 6, 8, 9, 12, 13, 14, 16, 17, 19, and 20 are classified as being intermediately contaminated since their PCB concentrations are less than 1.0 ppm and greater than 0.05 ppm total PCB's. Station 6 has intermediate levels of PCB's in the upper 5 cm of the sediment, but concentrations drop with increasing depth.

Station 20 did not have detectable PCB's in the upper 5 cm of the sediment column, but intermediate concentrations of PCB's are present below 15 cm. There is a possibility that recent scouring and dredging or a discontinuation of PCB input may have occurred at this station.

At stations 7 and 11, PCB concentrations are less than 0.05 ppm. Both of these stations are located in the outer harbor area near the reference station 12.

Generally, there is a decrease in PCB concentration with sediment depth. Besides station 20, stations 9, 14 and 19 did not follow the pattern of lower PCB concentrations with depth. For three stations (4, 7, 11, and 12) no apparent pattern (within statistical limits) of PCB's exist. Eleven of the remaining stations, within statistical range, show decreasing PCB levels with sediment depth.

TABLE D-1

PCB concentrations (ppm w/w basis) for Baltimore Harbor stations (Figure D-1) by depth.

Station	Depth (ft)	Depth (cm)	Aroclor 1260	Aroclor 1248	Total
1[1]	0.16	5	84.19	----	>84.19
	0.5	15	2.41	----	> 2.41
	1.0	30	0.59	----	> 0.59
	2.0	61	3.11	----	> 3.11
2	0.16	5	1.26	0.87	2.13
	0.5	15	0.91	0.54	1.45
	1.0	30	0.60	0.39	0.99
	2.0	61	0.32	0.13	0.45
3	0.16	5	1.70	0.57	2.27
	0.5	15	0.97	0.76	1.73
	1.0	30	0.89	0.76	1.65
	2.0	61	0.71	0.64	1.35
4	0.16	5	0.84	0.51	1.35
	0.5	15	0.94	0.71	1.65
	1.0	30	0.80	0.39	1.19
	2.0	61	0.71	0.55	1.26
5	0.16	5	2.10	3.50	5.60
	0.5	15	1.20	1.50	2.70
	1.0	30	0.24	0.14	0.38
	2.0	61	0.05	< 0.05	> 0.05
6	0.16	5	0.10	0.11	0.21
	0.5	15	<0.05	<0.05	<0.05
	1.0	30	<0.05	<0.05	<0.05
	2.0	61	<0.05	<0.05	<0.05

TABLE D-1

PCB concentrations (ppm w/w basis) for Baltimore Harbor stations (Figure D-1) by depth. (continued)

Station	Depth (ft)	Depth (cm)	Aroclor 1260	Aroclor 1248	Total
7	0.5	15	<0.05	<0.05	<0.05
	1.0	30	<0.05	<0.05	<0.05
	2.0	61	<0.05	<0.05	<0.05
8	0.16	5	0.16	0.11	0.27
	0.16	5	0.15	0.22	0.37
	0.5	15	0.06	0.07	0.13
	1.0	30	<0.05	<0.05	<0.05
	2.0	61	<0.05	<0.05	<0.05
9	0.16	5	0.41	0.23	0.64
	0.5	15	0.12	<0.05	0.12
	1.0	30	0.64	0.32	0.96
	2.0	61	0.14	0.06	0.20
10	0.16	5	0.29	0.83	1.12
	0.5	15	0.17	0.29	0.46
	1.0	30	0.19	0.24	0.43
	2.0	61	0.17	0.16	0.33
11	0.16	5	<0.05	<0.05	<0.05
	0.5	15	<0.05	<0.05	<0.05
	1.0	30	<0.05	<0.05	<0.05
	2.0	61	<0.05	<0.05	<0.05
12	0.16	5	<0.07	<0.05	>0.07
	0.5	15	0.06	<0.05	>0.06
	1.0	30	<0.05	<0.05	<0.05
	2.0	61	0.07	0.11	0.18

TABLE D-1

PCB concentrations (ppm w/w basis) for Baltimore Harbor stations (Figure D-1) by depth. (continued)

Station	Depth (ft)	Depth (cm)	Aroclor 1260	Aroclor 1248	Total
13	0.16	5	0.32	0.28	0.60
	0.5	15	0.33	0.14	0.47
	1.0	30	0.30	0.11	0.41
	2.0	61	<0.05	<0.05	<0.05
14	0.16	5	0.06	0.06	0.12
	0.5	15	<0.05	<0.05	<0.05
	1.0	30	<0.05	<0.05	<0.05
	2.0	61	0.10	0.07	0.17
15	0.16	5	1.48	0.84	2.32
	0.5	15	0.55	1.32	1.87
	1.0	30	0.25	0.14	0.39
	2.0	61	<0.05	0.05	0.05
16	0.16	5	0.10	0.09	0.19
	0.5	15	0.07	0.06	0.13
	1.0	30	0.05	<0.05	0.05
	2.0	61	<0.05	<0.05	<0.05
17	0.16	5	0.47	0.31	0.78
	0.5	15	0.57	0.19	0.76
	1.0	30	0.06	<0.05	0.06
	2.0	61	0.08	0.10	0.18

TABLE D-1

PCB concentrations (ppm w/w basis) for Baltimore Harbor stations (Figure D-1) by depth. (continued)

Station	Depth (ft)	Depth (cm)	Aroclor 1260	Aroclor 1248	Total
18	0.16	5	0.61	0.64	1.25
	0.5	15	0.22	0.23	0.45
	1.0	30	0.14	0.15	0.29
	2.0	61	0.08	<0.05	0.08
19	0.16	5	0.06	0.05	0.11
	0.5	15	0.22	0.25	0.47
	1.0	30	0.17	0.21	0.38
	2.0	61	0.25	0.28	0.53
20	0.16	5	<0.05	<0.05	<0.05
	0.5	15	0.28	0.43	0.71
	1.0	30	0.23	0.12	0.35
	2.0	61	0.12	0.10	0.22

---

[1] Aroclor 1260 was masking 1248 values so that total values may be substantially higher for this one sample set.

In Figure D-2, PCB concentrations for the Baltimore Harbor stations are plotted as a function of depth and channel length (in kilometers). It is obvious, except for the PCB concentrations at station 20, that from station 1 to 18, high PCB loading is present in the sediments. A localized high concentration of PCB's is observed at stations 5 and 15.

From station 9 to 6 (Figure D-2) and except for stations 18 & 16, total sediment PCB concentrations are greater than 0.05 ppm but less than 1.00 ppm. At stations 7 and 11, PCB's have essentially disappeared from the sediment (no values are available for station 7 at the 5 cm level). PCB's are also starting to disappear at the lower depths from stations 8 to 11.

In Figure D-3, the relationship of Aroclor 1248 to 1260 concentrations is plotted. There is a significant (at $p<0.001$, $r=0.91$) correlation between 1248 and 1260 values in the sediments. Three significant outliers occur. At station 3, the level of 1260 is over three times greater than the 1248 value. At station 15 for the 15 cm depth, the 1248 concentration is almost 2.5 times greater than the 1260 concentration. At station 10, the 1248 value is also 2.5 times greater than the 1260 value at the 5 cm depth. These factors may be a result of industrial usage patterns.

D.4 DISCUSSION

Sediment concentrations of PCB's except for special cases at station 20 (low level) and stations 5, 15, and 18 (high levels) tend to be elevated from station 19 to station 1 - the inner seven kilometers from approximately Colgate Creek through the Northwest Branch. From station 9 (Curtis Bay) to station 12 (Old Road Bay), PCB concentrations are greater than 0.05 ppm, but less than 1.00 ppm of total PCB's. Outside of the entrance to the harbor, PCB

Figure D-2 - PCB concentrations as a function of depth and channel length in Baltimore Harbor. Dark shading indicates PCB concentrations greater than 1 ppm, lateral markings indicate PCB concentrations less than 1 ppm but greater than 0.05 ppm, and clear areas indicate PCB concentrations less than 0.05 ppm.

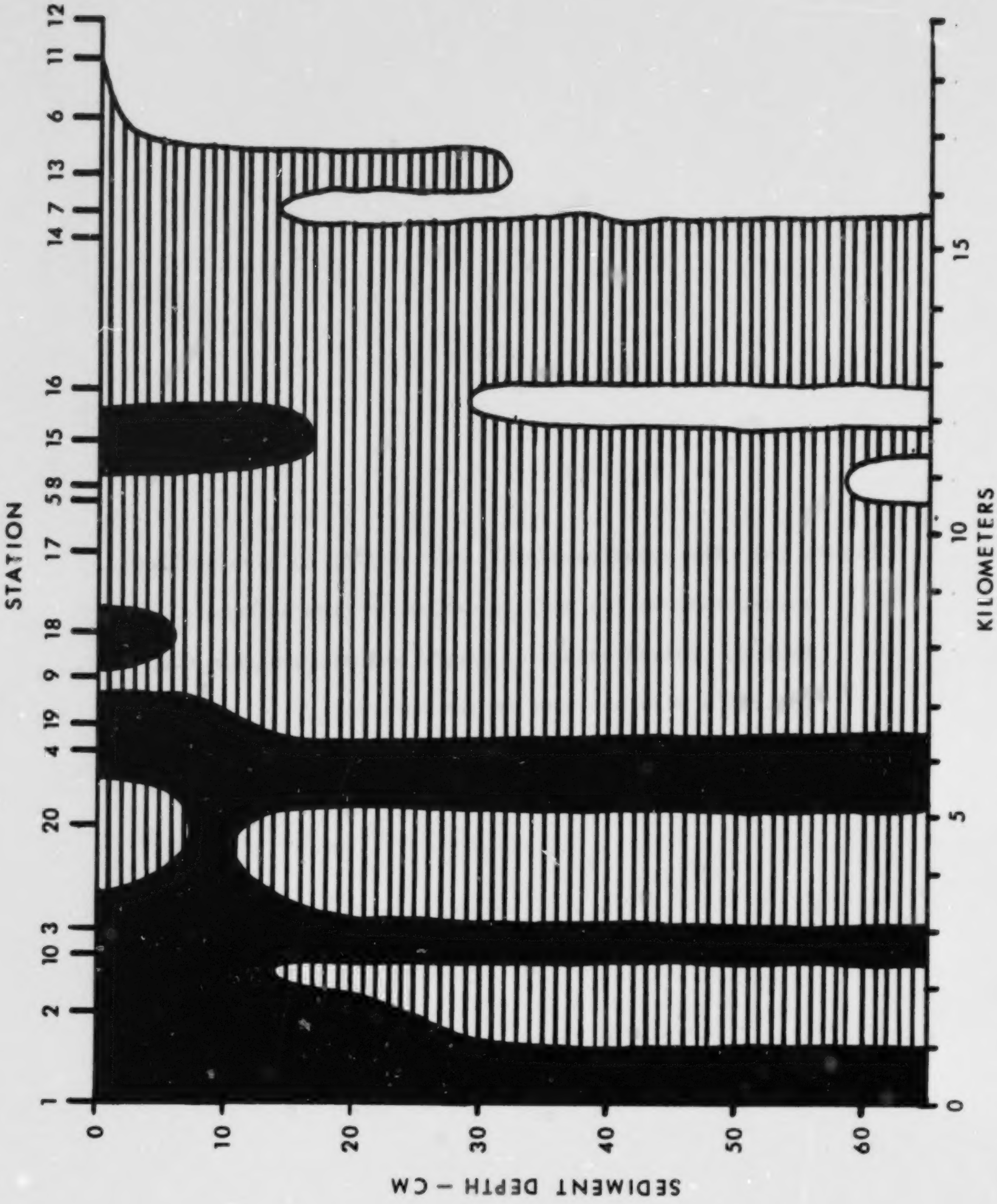
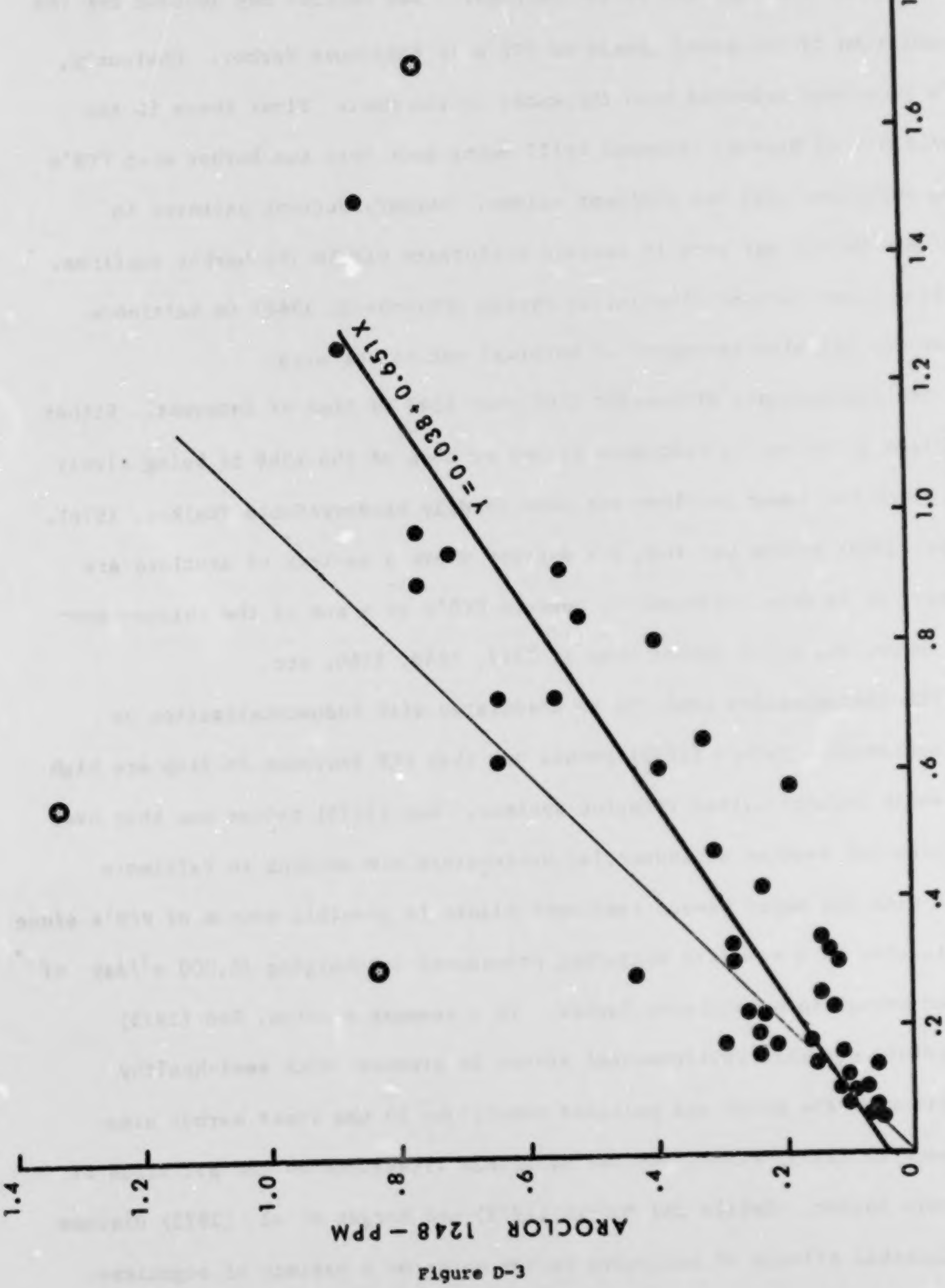

STATION
12
11
6
13
7
14
16
15
5
8
17
18
9
19
4
20
3
10
2
1
KILOMETERS
0
5
10
15
SEDIMENT DEPTH – CM
0
10
20
30
40
50
60

Figure D-2

Figure D-3 - The relationship of Aroclor 1248 to Aroclor 1260 concentrations (in ppm) in sediments from Baltimore Harbor. Paired values or single values less than 0.05 ppm PCB's were not used in the analysis.



Y=0.038+0.651 X
AROCLOR 1260 — PPM
AROCLOR 1248 — PPM
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

Figure D-3

concentrations drop to levels below 0.05 ppm (station 12 has low PCB levels, but primarily 1260 appears in the samples). Two factors may account for the accumulation of increased levels of PCB's in Baltimore Harbor. Obviously, PCB's have been released into the water in the past. First there is the possibility of present releases still being made into the harbor with PCB's being entrapped into the sediment column. Second, current patterns in Baltimore Harbor may tend to contain pollutants within the harbor confines. A unique three-layered circulation system (Pritchard, 1968) in Baltimore Harbor may minimize transport of material out of the area.

The predominance of Aroclor 1260 over 1248 is also of interest. Either more 1260 is in use in Baltimore Harbor or some of the 1248 is being slowly lost since the lower Aroclors are more readily biodegradable (Walker, 1976). Walker (1976) points out that for systems where a variety of Aroclors are present, it is more important to measure PCB's as a sum of the chloro-homologs (mono, di, etc.) rather than as 1242, 1248, 1260, etc.

PCB contamination tends to be associated with industrialization or with accidents. Walker (1976) points out that PCB residues in fish are high in heavily industrialized riverine systems. Koo (1975) points out that over 170 potential sources of industrial wastewaters are present in Baltimore Harbor with two major sewage treatment plants (a possible source of PCB's since chlorination is a standard operating procedure) discharging 76,000 m^3/day of treated sewage into Baltimore Harbor. In a summary section, Koo (1975) also points out that environmental stress is present, with semi-healthy conditions at the mouth and polluted conditions in the inner harbor area. Pfitzenmeyer (1975) summarizes the available literature on the pollution of Baltimore Harbor. Heinle and Morgan (1972) and Morgan et al. (1973) discuss the sublethal effects of Baltimore Harbor water on a variety of organisms.

The input of PCB's into estuarine waters is the result of a variety of processes (Walsh, 1972) - (1) agricultural runoff, (2) industrial/ municipal discharge, (3) drift and rainfall and (4) accidental/careless discharge. Although PCB's are relatively insoluble in water, they may be made soluble by humic acids as occurs with pesticides (Wershaw et al., 1969). PCB transport may come not only from water movement, but also from the involved process of sediment flocculation and resuspension - a phenomena in the estuarine system. In addition, differential solubilities of PCB's may result in precipitation (Walsh, 1972). No matter what the level of PCB input may be to a system, the possibility exists that biomagnification and bioaccumulation could occur to an extent which could be damaging to a population or to the entire aquatic community.

Any analysis of PCB accumulation in sediments is complicated by the relative insolubility of the different formulations. Most of the crystalline PCB's are insoluble, however, resinous and liquid PCB's solubilize in organic solvents; thinners and oils (Reynolds, 1971). For oceanic waters, 90% of the PCB's are dissolved (Harvey, unpublished data in Duce et al., 1974).

Sediments appear to be a pool for PCB's in estuarine and marine systems (Duce et al., 1974) with concentrations of sediment PCB's inversely proportionate to water depth. Harvey (unpublished data, Duce et al., 1974) found PCB concentrations ranging from 500 ng/g sediment (ppb) in inshore Massachusetts to 0.3 ng/g sediment in the Hatteras Plain. For San Francisco Harbor, PCB's range from 0.026 to 0.833 ppm (Pacific Northwest Laboratories, 1974). Duke et al. (1970), investigating an industrial spill of Aroclor 1254, found sediment containing up to 486 ppm of PCB's.

Hom et al. (1974) observed PCB deposition rates of 1.2×10^{-4} g/m^2/year in the Southern California Bight.

Given either a value for sediment or water PCB content, what are the possible concentrations of PCB's in estuarine populations or communities. Although some detailed analyses of ocean water have been made, very few studies have been concerned with transfer mechanisms of PCB's in estuarine and coastal systems where major ecological effects could occur (Duce et al., 1974). An organic may become present in very low quantities within an aquatic community. Based on a variety of factors such as salinity, sediment/solution ratio, and concentrations, PCB's may accumulate in populations and communities. It appears that chemical and some physical factors such as temperature, pH, Eh, and dissolved oxygen are not important when dealing with PCB desorption from sediments. Initially, a primary producer or heterotroph will take up the toxic material from either the water column or from deitrus and suspended sediments. Primary consumers will further concentrate toxic materials. Eventually, upper components (fish, mammals, birds, etc.) of an aquatic ecosystem will concentrate the material 10^3 to 10^6 - fold. Within a population, the problem is bioaccumulation, within a community the problem is biomagnification. Bioaccumulation or biomagnification of toxic materials may reveal itself in two ways - acute effects and sublethal effects. Acute effects, such as mortality and increased vulnerability to predation, could occur. Sublethal effects, by definition, are the typical consequence of biomagnification and bioaccumulation in aquatic communities.

Bioaccumulation in a population is directly related to the lipophylicity of PCB's and the overall bioenergetics of the population (Norstrom et al., 1976). Strongly lipophylic agents will probably be assimilated at maximal or near-maximal efficiency. Thus, the uptake rate of these residues will fall within limits set by populational characteristics such as metabolic rate and growth, which in turn are a function of the environmental variables acting on that population (Norstrom et al., 1976).

The level of a residue within a single organism of a population is a function of exposure, dose and absorption of the residue into the organism. Within the organism, the concentration becomes a function of residue distribution, deposition, remobilization and excretion. For lipophylic compounds, prime areas of deposition are organisms such as fish, mammals and birds.

Wildish and Zitko (1971) propose that PCB uptake may be accomplished by either absorption in the gut from food or water or through the body surface. Harvey et al. (1974) find PCB concentrations in Atlantic plankton ranging from 200 μg/kg to 100 μg/kg wet weight - samples with high PCB concentrations contained large numbers of phytoplankton. Duce et al. (1974) report that unicellular algae can concentrate ng/g quantities of PCB's as much as ten-thousandfold. However, herbivores feeding on the same algae could only accumulate PCB's two- to fivefold; larval fish also could only accumulate PCB's two- to fivefold from feeding on the herbivores (Duce et al., 1974). However, sediment-feeding invertebrates living in an area of high PCB's could easily ingest large quancities of PCB's. This may shorten the link between the higher trophic levels.

Wildish and Zitko (1971) find that PCB uptake in amphipods increases with increasing PCB concentration although the rate of uptake decreases after 4 to 6 hours exposure. Sanders and Chandler (1972) note that bioaccumulation in invertebrates for short term exposures range from 160 to 6,300 times the water concentration, but bioaccumulation in longer exposures results in PCB accumulation from 27,000 to 48,000 times the water concentration. In fish (Hansen et al., 1971) accumulation rates occur at

10,000 to 50,000 times the environmental levels. Vreeland (1974) points out, in a series of experiments with oysters, that PCB's containing more chlorine atoms (such as 1260) accumulate in greater amounts. Based on Vreeland's data, it was calculated the correlation of degree of chlorination versus the log of the equilibrium isomer concentration and found a highly significant (r=0.97) relationship between the numbers of chlorines on the parent biphenyl and isomer concentration in oysters. For any increase of 1 pptr in the water, oysters accumulate 1-2 ppb for the dichloro isomer to 48 ppb for the hexachloro isomer (Vreeland, 1974). Generally, Vreeland (1974) reports equilibrium of PCB content in oysters with environmental conditions approximately one month after exposure. In Florida, Duke et al. (1970) found that many estuarine species accumulated 1254 in amounts from 1.0 to 184 ppm with a sediment concentration of 486 ppm (maximum).

Although high concentrations of PCB's do accumulate in mammals, fish and birds, many factors such as lipid content, degree of chlorination, physical and chemical factors, etc. may determine actual PCB concentrations in aquatic food webs. Norstrom et al. (1976) have developed a model for pollutant accumulation based on pollutant biokinetics linked to fish energetics. The uptake rate of pollutants is dependent on both species-specific factors (metabolism, growth, lipid content, etc.) and environmental factors (salinity, temperature, food, etc.).

As described before, bioaccumulation is a populational characteristic (really an individualistic phenomena). Once a pollutant is part of a living organism, concern then shifts to the problem and process of biomagnification through food webs and trophic assemblages. Biomagnification is obviously important, in relation to human health, if the upper components of the food chain are accumulating PCB's in large enough amounts to cause damage upon human consumption.

Of equal importance to the problem of human health, is the effect of PCB's on community structure and function. Moore and Harriss (1972) found that radiocarbon uptake by the phytoplankton is strongly inhibited at 5 ppb of Aroclor 1242 and 1254 affecting lower trophic dynamics. In a related paper, Mosser et al. (1972) noted that competitive interactions between two species of algae are altered at PCB concentrations as low as 1 ppb. Nebeker et al. (1974) studied the effect of PCB's on fish reproduction and survival; found growth and reproduction still occurring at and below 1.8 ppb of 1254 and at or below 5.4 ppb 1242. In their study, the newly hatched larvae were extremely sensitive to 1254 and 1242. Growth of the larvae was affected at PCB levels greater than 2.2 ppb. In a related study, Schimmel et al. (1974) studied effects of 1254 on sheepshead minnows and found poor survival of fry at PCB concentrations at or above 0.1 ppb, although embryos developed at 10.0 ppb. The above studies point out that PCB's may affect community structure by affecting growth and reproduction.

Obviously, PCB's are toxic, but are usually less toxic than compounds such as DDT and dieldrin (Walsh, 1972). Generally in aquatic systems, toxicity due to a substance is rarely observed. However, sublethal effects of that toxicant are more important especially if the compound is an accumulator with a long biological half-life.

Toxicity of PCB's is reviewed by Dustman et al. (1971), Fishbein (1974), Walsh (1972), Walker (1976) and Reynolds (1971). At present, the majority of PCB toxicology still deals with mammals and birds, although more emphasis is being placed on aquatic organisms.

On a sublethal basis, PCB's tend to produce a variety of pathological conditions in man and rats including a variety of changes in hepatic function (Allen and Abrahamson, 1973). PCB's are embryolethal, teratogenic and carcinogenic plus also being immunosuppressive (Fishbein, 1974). Other sublethal effects are associated with community and populational processes such as growth, reproduction and competition (Moore and Harriss, 1972; Mosser et al., 1972; Nebeker et al., 1974; Schimmel et al., 1974; Nebeker and Puglisi, 1974). Risebrough et al. (1968) observed that only a few molecules of chlorinated hydrocarbons are needed for steroid breakdown - an important point when dealing with testicular and ovarian function or normal endocrine pathways in aquatic animals.

Given the above information and the data from this study, what are the possible relationships of PCB levels in Baltimore Harbor sediments to plants and animals on a local basis. First, there are some assumptions before the analysis. One, the water concentration of PCB's is in some equilibrium with the sediment concentration. Second, the organism is neither hyper- nor hyporich in lipid concentration. Third, each organism has an equal probability of accumulating PCB's based on populational and physiological attributes inherent for that species. Fourth, the organisms are exposed long enough to take up PCB's to equilibrium.

For this analysis, information from three studies is required (Duke et al., 1970; Forns, 1972; and Munson, 1972). Duke et al. (1970) found 486 ppm of 1254 in sediment and from 1.0 to 184 ppm in a variety of fish and invertebrates. In this case, the animal to sediment ratio varies from 0.0021 to 0.379. Munson (1972) observed 1242 concentrations in Chester River sediments ranging from 0 to 300 ppb with average values from 53 to 110 ppb. (Munson also observed that PCB's bind to the sediment with an inverse relationship of concentration to particle size.) In the biota, Munson (1972) observed (averages) for oysters - 55 ppb, clams - 58 ppb, fish - 185 ppb and crabs - 20 ppb. Using a mean value of 87 ppb for Chester River sediment PCB concentrations, the animal to sediment ratio varies from 0.22 for crabs, 0.63 for oysters, 0.66 for clams and 2.2 for fish. Forns (1972) found PCB levels of 286 ppb of 1242 and 79 ppb of 1254 in plankton (primarily zooplankton and values are maximum possible values). For zooplankton, the animal to sediment ratio is 4.2.

Consider two areas of Baltimore Harbor, the inner heavily contaminated area with sediment PCB concentrations greater than 1000 ppb and the other areas with PCB's greater than 50 ppb. For zooplankton in the inner harbor, PCB's may accumulate up to 4200 ppb. Fish may accumulate 2200 ppb, clams - 660 ppb, oysters - 630 ppb and crabs 200 ppb. Using the data from Duke, accumulation would range from 2.1 to 379 ppm. In areas with sediment PCB levels of 50 ppb, zooplankton would accumulate 210 ppb, fish - 110 ppb, clams - 33 ppb, oysters - 32 ppb and crabs - 11 ppb.

Based on the sublethal information now known, it appears that PCB levels in inner Baltimore Harbor are high enough to cause serious problems in both population dynamics and community structure. Emphasis should now be placed on monitoring actual PCB levels in organisms from Baltimore Harbor.

D.5 SUMMARY

Polychlorinated biphenyls were assayed in sediment cores (at four depths) from 20 stations in Baltimore Harbor. Assay techniques included PCB extration and detection through electron capture gas-liquid chromatography. Eighty Aroclor 1260 and 76 aroclor 1248 samples were run. PCB concentrations were high (greater than 1.0 ppm total PCB's) at stations 1, 2, 3, 4, 5, 10, 15, and 18.

The highest level was 84.2 ppm of aroclor 1260 at station 1 in the Inner Harbor area. Heavy concentrations of PCB's (5.6 ppm) were also observed at station 5 in Bear Creek. Non-existant or low quantities of PCB's were observed at stations 7 and 11 with low levels at stations 6, 8, 12, 14, and 16. Generally, high levels of PCB's correlated to large amounts of hexane extractable total hydrocarbons.

Levels of PCB's within the Inner Harbor area as well as Colgate and Bear Creeks are high enough to cause significant biological effect if exposure to the PCB-laden sediments is of a long enough duration.

PCB soluability is low in water and higher in oils and fats. The coincidental occurrence of PCB's and hexane extractable materials at some stations strongly suggests that exceptional care must be taken in handling materials from such sites to preclude significant PCB pollution at areas of sediment placement.

APPENDIX E

BIOASSAY OF BALTIMORE HARBOR SEDIMENTS

E. 1 LITERATURE REVIEW

Literature pertaining to the biology of Baltimore Harbor prior to 1971 was reviewed briefly by H. T. Pfitzenmeyer (Center for Environmental and Estuarine Studies, 1975). He stated that natural resources of the Harbor rapidly declined before the turn of the century. There were 3,800,000 square yards of oyster bars within the Harbor, northwest of a line from Old Road River to Sollers Point, in 1884. In 1907 the northern limit of all oyster grounds was Rock Point at the entrance to the Harbor, and bottoms above Bodkin Point were not recommended for oyster culture. Yates (1913) made a survey of oyster bars in Chesapeake Bay in 1906-1912, and no oyster bars were shown for Baltimore Harbor.

Olson, et al, (1941) studied the effects of industrial pollution of copperas, Fe $(OH)_3$, on the biological productivity of Curtis Bay and nearby water in Baltimore Harbor. This red-brown precipitate appeared to decrease dissolved oxygen concentration of water during the summer, affecting plankton by asphyxiation and then indirectly affecting higher organisms. In a laboratory study, the floc of copperas caused a heavy coagulum on gills of killfish (Fundulus), silversides (Menidia), and white perch (Morone americana). They believed that this red-brown precipitate accumulated on the bottom and contributed to a marked ecological disturbance of the area. Later, Davis (1948) also studied this copperas-polluted area of Curtis Bay and confirmed the Olson, et al, (1941) findings; but he found more diatoms present per liter in the polluted area than in the relatively unpolluted area.

Weiss (1950) investigated the possibility of an outbreak of marine wood borers caused by a reduction in pollution of Baltimore Harbor. No molluscan or crustacean borers were found in the Harbor. Of the three species of wood borers occurring in this latitude, sporadic sets by Bankia gouldi might occur. Salinities were too low for Teredo navalis and Limnoria lignorum. There was no evidence supporting the belief that a reduction in pollution of the Harbor will increase shipworm infestation.

Garland (1952) made the first extensive water quality survey of Baltimore Harbor and the Patapsco estuary. He stated that in some seasons of the year fishing was good at the entrance to the Harbor, but within the Harbor fishing and crabbing diminished during the previous quarter of a century and had virtually stopped. This, he concluded, resulted from waste discharges.

Stroupe, et al, (1961) investigated the physical hydrography of Baltimore Harbor to determine the flushing rate and hydrographic mechanisms of the Harbor. They suspected that fish and other animals were probably not affected by the range of pH which occurred in the Harbor, and that any deleterious effects might have resulted from increase in carbon dioxide. However, high carbon dioxide concentration was favorable for the growth of phytoplankton and marine plants.

Hohn and Hellerman (1966) studied diatoms in Lewes-Rehoboth Canal, Delaware, and Baltimore area of Chesapeake Bay. They described four new species from Curtis Bay, a major tributary of the Harbor, in the vicinity of Sledds Point. These were *Diploneis hormopunctata*, *Navicula agmastriata*, *N. cumvibia* and *N. taraxa*.

Chesapeake Biological Laboratory (Center for Environmental and Estuarine Studies, 1975) conducted a comprehensive biological study of Baltimore Harbor in 1970-1971. Four major biological groups were studied: fish eggs and larvae by W. L. Dovel; invertebrate benthos by H. T. Pfitzenmeyer, adult fish by M. L. Wiley, and blue crabs by R. L. Lippson and R. E. Miller. The results were summarized and edited by T. S. Y. Koo. It was found that the water column in Baltimore Harbor still supported many species of fish, but the bottoms were unfit for ground fish and for many species of benthic macro-invertebrates.

Dyer (1971) of the Maryland Fish and Wildlife Administration investigated fish kills of Bear Creek on September 16, 1971; and Riggin (1972) of the Maryland Water Resources Administration investigated water quality of effluents and offshore waters at Bethlehem Steel Corporation Sparrows Point Plant. Heavy metals were found in toxic concentrations in water off Sparrows Point and cited as a major contributing factor for fish kills in Bear Creek. Acids, caustics, cyanides, ammonia, and phenol were also detected in acutely toxic levels in the Harbor water.

Villa and Johnson (1974) of the Environmental Protection Agency's Annapolis Field Office, Region III, studied the heavy metal contamination of Baltimore Harbor sediments. They indicated that heavy metal contamination might be a major contributing factor to the biological deterioration of benthic communities of the Harbor.

Maryland Environmental Service (1974) studied the water quality of the Harbor from 1968 to 1971 and produced a Draft Report. In this project, the phytoplankton were studied by G. A. Bowman, St. Mary's College of Maryland; and chronic bioassay of the Harbor water on clams, copepods and fish was conducted by D. R. Heinle and R. P. Morgan, Chesapeake Biological Laboratory. Chlorophyl a concentration and biomass suggested that the Harbor was not highly eutrophic but that the phytoplankton community was less diverse than that in the Chesapeake Bay. The results of chronic bioassay showed that there were some effects of the Harbor water on the survival of clams (Macoma balthica) and inhibitory effects on brain acetylcholinesterase activity in two species, the hogchoker (Trinectes maculatus) and the white perch. Otherwise, there was no clear indication of damaging effects. The same report indicated that fishermen were observed in the Inner and Outer Harbor and on the Patapsco River bridge. In 1972, a 28-pound bluefish was taken at Ft. Smallwood in the Outer Harbor and won the Sun Paper's Annual Sport Fishing Contest.

Morgan, et al, (1976) studied antibiotic resistant bacteria in the Upper Chesapeake Bay. Of nine water sampling stations, three stations were located in Baltimore Harbor. The results showed a three-fold or greater increase in the number of antibiotic resistant coliforms, extending up the Bay from the Chesapeake Bay bridge north to Baltimore Harbor. The increase in number of antibiotic resistant bacteria in the Harbor and its vicinity suggested that sewage effluents had a detectable influence on water quality.

E.2 INTRODUCTION

Baltimore Harbor receives great amounts of domestic and industrial wastes from the City of Baltimore (Maryland Environmental Service, 1974). The Harbor sediments have been known to contain high concentrations of organic silts (Center for Environmental and Estuarine Studies, 1975), volatile solids, mainly oil and grease (Garland, 1952), ferric hydroxides (Olson, et al, 1941; Davis, 1948), and iron and heavy metals (Villa and Johnson, 1974). Iron sulfate contributes a large portion of the total industrial discharge to the Harbor (Garland, 1952). Chemical constituents and toxic contaminants of the polluted sediments of Baltimore Harbor are extremely complex, and their total chemical load and pollution load are not known. It is impossible to select a small number of chemical parameters for a conventional chemical test, such as a bulk test or the recently developed elutriate test, for determining the toxic level of such sediments. In order to determine the toxic level of the Harbor sediments, Lee and Plumb (1974) suggested that a sediment bioassay be made.

For this study, a bioassay was designed for determining the total biological impact of sediments from a set of stations widely distributed over the Harbor system and including stations of known high pollution load and of relatively low load. Since only a partial chemical analysis could be conducted at each site, it is impossible to assign with certainty the cause or causes of biological damage, although some coincidences could be considered. Such a bioassay series determines the range of toxicities likely to be found, provides a ranking of the biological threat in various locations, and suggests the more extensive research which would be required for full quantification of effects and determination of their precise chemical or physical causes. The objectives of this study were: (1) to determine gross toxicity of representative Harbor sediments for several appropriate organisms; (2) to supplement the chemical data of the Harbor sediments to further define and describe the problem areas of the Harbor; and (3) to suggest the possible environmental effects of dredging or other corrective actions.

E. 3 PROCEDURES

Nine sediment sampling stations were designed, representing the various polluted parts of Baltimore Harbor noted in earlier studies (Figure E-1). At each station, about thirty gallons of sediment was collected on June 9, 1976 from the top one foot of bottom material. Salinity and water temperature at the time of sampling are shown in Table E-1. Of the total sample, about a half-gallon was removed for bulk chemical analyses

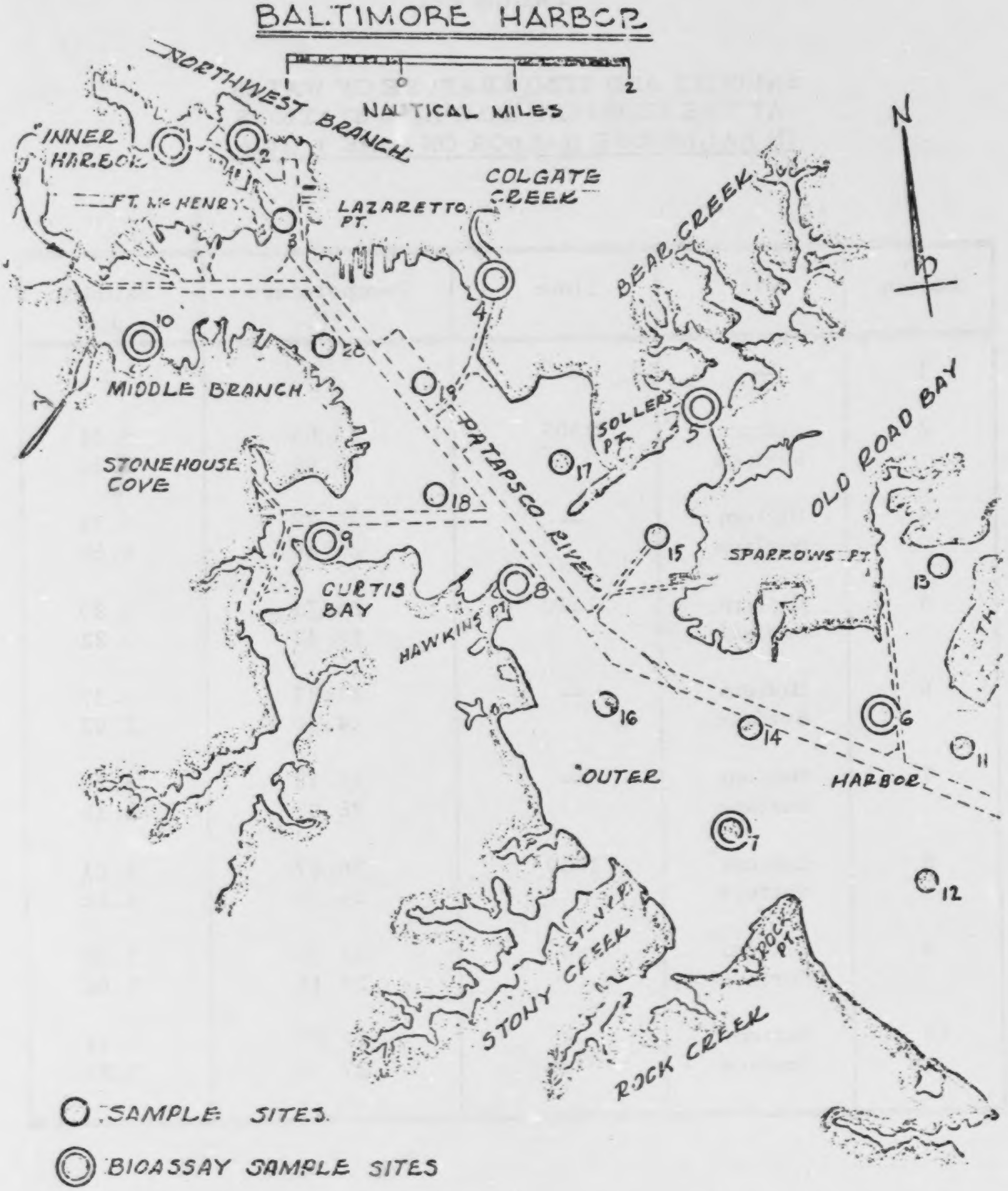

BALTIMORE HARBOR
1
0
1
2
NAUTICAL MILES
N
NORTHWEST BRANCH
INNER HARBOR
1
2
FT. McHENRY
3
LAZARETTO PT.
COLGATE CREEK
4
BEAR CREEK
10
20
19
MIDDLE BRANCH
PATAPSCO RIVER
SOLLERS PT.
5
OLD ROAD BAY
STONEHOUSE COVE
17
18
9
15
SPARROWS PT.
13
CURTIS BAY
8
HAWKINS PT.
16
14
6
11
OUTER
HARBOR
7
12
STONY PT.
STONY CREEK
ROCK PT.
ROCK CREEK
SAMPLE SITES
BIOASSAY SAMPLE SITES

Figure E-1

TABLE E-1

SALINITY AND TEMPERATURE OF WATER AT THE SEDIMENT SAMPLING STATIONS IN BALTIMORE HARBOR ON JUNE 9, 1976

Station	Site	Time	Temperature °C	Salinity ppt
1	—	—	—	—
2	Bottom	1305	22.63	5.42
	Surface		23.94	5.36
4	Bottom	—	20.78	7.78
	Surface		25.80	4.60
5	Bottom	1530	26.71	4.20
	Surface		28.22	3.22
6	Bottom	—	21.83	5.37
	Surface		24.50	2.92
7	Bottom	—	23.18	5.26
	Surface		26.07	4.16
8	Bottom	1730	26.07	5.03
	Surface		26.58	4.22
9	Bottom	1800	22.06	5.72
	Surface		25.15	5.02
10	Bottom	—	21.87	5.12
	Surface		27.39	3.83

of heavy metals, sediment moisture and hexane extracts. The rest of the sample was brought back to the laboratory and kept hydrated in anaerobic condition in the cold room at 4° C (Bricker, 1975). This sediment sample was used as experimental material in fish bioassay. Non-toxic fuller's earth was used as a reference material.

Sea water of five ppt salinity, about the mean salinity of the Harbor water (Garland, 1952; Skelly, 1973), was made by mixing synthetic sea salts with dechlorinated, aged tap water. This water was used as diluting water for the sediments and control water in the study.

Two species of fish and one species of clam found in Chesapeake Bay were used as test organisms. They were mummichogs (Fundulus heteroclitus), spot (Leiostomus xanthurus) and soft-shell clams (Mya arenaria). Mummichogs were collected from the Patuxent River estuary about five miles upstream from Solomons, Maryland. Spot were collected from the Patuxent River about a quarter mile downstream from the Rt. 321 bridge. Soft-shell clams were also collected from the Patuxent River near Solomons by Dr. R. Morgan and had been held in a Bay water circulation tank for nearly a year at Chesapeake Biological Laboratory.

These three test species were brought back to the laboratory and acclimated in 5 ppt synthetic sea water for a week prior to the experiments. Acclimation temperature was 25°C for mummichogs and spot and 21°C for shoft-shell clams. The sizes of the test organisms were 43.05 ± 1.39 mm (mean ± standard errors) for mummichogs, 64.95 ± 4.19 mm for spot, and 31.08 ± 0.72 mm for soft-shell clams.

Four sets of static bioassay apparatus, each in 4' x 8' x 18" water bath, were set up. Each set had six 10-gallon test tanks. Each tank contained a 6" x 10" x 12" screen basket with a quarter-inch mesh to hold the test organisms and a $\frac{1}{150}$ horsepower submerged pump to stir the sediment-water mixture during the experiments. There was a space of about an inch between the bottom of the basket and the bottom of the tank. The pump was located at one end of the tank outside of the screen basket. In order to prevent sediment settlement on the tank bottom, the mixture was shot from the pump along the tank bottom surface to the other end of the tank and then the mixture flowed upward and backward into the screen basket. The test temperatures were the same as the acclimation temperature.

When a sediment sample at a station was to be used, the total sample was taken out of the cold room and stirred with a wooden paddle. After it was homogeneously mixed, about 10 gallons of the sediment was removed and mixed with 20 to 30 gallons of the synthetic sea water to make a stock sediment-water mixture. For each experiment, five different concentrations of the test sediment-water mixture were made from this stock sediment-water mixture by mixing to the desired dilution with the synthetic sea water in five test tanks. The sixth tank was filled with synthetic sea water and used as the control. Each tank contained 22 liters of the sediment-water mixture. The test sediment-water mixture and control water were stirred and aerated for at least 24 hours until the color of the mixture changed from black into grayish brown to eliminate high oxygen demands and to maintain an adequate dissolved oxygen level in the mixture for the test organisms. Ten fish or clams were transferred from the acclimation tank into each test tank. Mortality in each tank was checked at least every 12 hours over a 48-hour period. For each sediment station, at least two complete series of experiments were conducted. Criteria for death of mummichogs and spot were cessation of opercular movement and no response to poking. The death of soft-shell clams was indicated by open shells or no sign of closing shells when poked or resisting the pressure of opening shells with fingernails.

In the beginning and at the end of the 48-hour experiment, dissolved oxygen, pH, temperature, salinity, suspended solids, dissolved solids, total solids, and turbidity of the test sediment-water mixture in each tank were determined. Dissolved oxygen, pH, temperature, salinity and turbidity were determined by meters. Suspended solids and dissolved solids were determined by standard methods (American Public Health Association, 1971). Water quality and mortality data of the test organisms in this study are presented in Tables E-10 through E-37, located at the back of this appendix.

E.4 RESULTS

E.4.1 Pollutants in Bioassay Sediment/Samples

For each of the nine bioassay stations, the Harbor sediment samples were analyzed for moisture, hexane extracts, and heavy metal concentrations (bulk analyses). Their averages, standard deviations, and coefficients of variation were calculated (Table E-2). There was a wide variation among the stations in the contents of these chemicals. Moisture was highest at Station 8 and followed in decreasing order by Stations 9, 5, 2, 4, 1, 6, and 10. Compared to the other parameters, moisture was least variable from one station to another. The quantity of soluble material extracted by hexane was highest at Station 5 followed in decreasing order by Stations 2, 4, 1, 10, 8, 6, 9, and 7. PCB concentration was also highest

TABLE E-2

MOISTURE, HEXANE EXTRACTS, PCB's AND HEAVY METAL CONTENTS (BULK ANALYSES) DETERMINED FOR BALTIMORE HARBOR SEDIMENT SAMPLES USED IN BIOASSAY, AND MUMMICHOG 24 HR-TLm VALUES FOR SUSPENDED SOLIDS

Station No.	Moisture %	Hexane Extracts mg/Kg	PCB's mg/Kg	Metals, mg/Kg									Mummichog 24 Hr-TLm Values
				As	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
1	67.65	9,600	-	229	2.65	7	1,810	580	320	79	510	1,010	11.79
2	87.33	17,600	1.26	75	2.78	15	1,460	1,830	510	190	620	1,400	4.93
3/4	75.62	10,600	0.84	53	0.85	43	470	2,300	570	63	460	430	4.65
5	90.47	21,500	2.10	71	1.15	45	4,300	580	560	93	800	5,500	0.63
6	65.31	2,900	0.10	13	0.45	2	200	150	710	81	340	1,070	25.96
7	66.59	2,300	<0.05	44	0.47	2	490	200	680	82	310	1,080	79.08
8	95.21	3,500	0.16	29	0.32	2	490	140	650	60	120	470	24.64
9	94.46	2,500	0.41	42	0.27	2	160	140	1,500	56	81	330	-
10	58.90	6,500	0.21	31	0.53	4	190	65	180	62	170	680	8.44
Average $\boxed{x}$	77.95	8,555.55	0.64	65.22	1.05	13.55	1,063.33	665.00	631.11	85.11	379.00	1,385.55	20.22
Standard Deviation (d)	14.05	7,001.81	0.53	64.52	0.98	17.77	1,347.42	824.43	363.73	41.28	241.06	1,577.99	25.60
Coefficient of Variation ($\frac{d}{x}$ 100)	18.02	81.84	82.8	98.93	90.48	131.14	126.72	125.87	57.63	45.50	63.60	113.89	127.87

* Sediment sample taken from the cores at the depth of 5 cm.

at Station 5 followed in decreasing order by Stations 2, 4, 9, 10, 8, 6, and 7. Of the heavy metals, Zn had the highest average concentration followed in decreasing order by Cr, Cu, Mn, Pb, As, Ni, Cd, and Hg. Coefficients of variation indicate that Cd, Cr, Cu, Zn, As, Hg, and PCB concentrations were more variable among the stations than Pb, Mn and Ni. The highest concentrations for any station were Cd, Cr, Zn, Pb, and PCB at Station 5; As, Hg, and Ni at Station 1; Cu at Station 4 and Mn at Station 6. It was clear from the analyses that the sediment at Station 5 was the most contaminated, and material from Station 7 was probably the least contaminated.

Correlation analyses were conducted to determine the relationships between chemical parameters determined for the nine stations (Table E-3). Hexane extracts, PCB, Pb, Cr, Zn, and Cd were significantly and positively correlated. A significant positive correlation was also found between Hg and Pb, Ni and As, and Cr and Cu, but the correlation coefficients were low. In contrast, Mn had a statistically insignificant negative correlation with hexane extracts, PCB and all heavy metals: it correlated with moisture positively, still at an insignificant level. Moisture was independent from all parameters studied. Because hexane mostly extracts non-polar organic materials from sediments, PCB and heavy metals which show a high degree of correlation with the hexane

TABLE E-3

CORRELATIONS AMONG HEAVY METAL CONTENTS, HEXANE EXTRACTS, PCB's, MOISTURE, AND MUMMICHOG 24 HR-TLm VALUES FOR BALTIMORE HARBOR SEDIMENTS STUDIED AT NINE STATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Hexane Extracts	-												
2. PCB's	0.96*	-											
3. Pb	0.90*	0.88*	-										
4. Cr	0.84*	0.91*	0.84*	-									
5. Zn	0.77*	0.83*	0.78*	0.93*	-								
6. Cd	0.76*	0.82*	0.72*	0.64	0.69*	-							
7. Hg	0.63	0.62	0.66*	0.45	0.17	0.18	-						
8. Ni	0.60	0.47	0.58	0.32	0.22	0.12	0.72*	-					
9. Cu	0.55	0.47	0.53	0.13	0.07	0.66*	0.50	0.48	-				
10. As	0.31	0.75	0.41	0.40	0.09	0.07	0.77*	0.14	0.15	-			
11. Mn	-0.37	-0.15	-0.39	-0.25	-0.17	-0.18	-0.43	-0.21	-01.9	-0.33	-		
12. Moisture	0.29	0.45	0.07	0.31	0.25	0.23	0.00	0.17	0.13	-0.13	0.56	-	
13. Mummichog 24 Hr-TLm	-0.65	-0.60	-0.42	-0.39	-0.21	-0.52	-0.41	-0.18	-0.43	-0.22	0.46	-0.29	-

---

* Significant at 5% level (P 0.05).

extracts such as Pb, Cr, Zn, and Cd might relate with occurrence of this organic fraction of the sediments. Moisture was least variable among stations and was independent from heavy metals and hexane extracts. It seems that moisture has no relationship with heavy metal concentrations in the Harbor sediments. In other words, the dissolved form of metals in the interstitial water of the sediments is perhaps so low compared to the particulate form in the sediments that the sediment moisture (interstitial water) is not a factor affecting bulk concentration of heavy metals in the sediments.

E.4.2 Properties of Bioassay Sediment-Water Mixtures

It is known that sediments in the scoured deposited condition can have high biological oxygen demands from deposited nutrients (Morton, 1976; Saila, et al, 1972) and high chemical oxygen demands from various iron sulfides and other chemicals (Slotta, 1974). When the sediments have been exposed to oxygenated water, the sediment oxygen demands have been known to increase eight to seventeen fold (Isaac, 1965; Reynolds, et al, 1973). In order to maintain an adequate dissolved oxygen level in the sediment-water mixture for the test organisms, the Harbor sediment-water mixtures in this study were stirred and aerated continuously for at least 24 hours prior to and during the experiments. As a result of the stirring and aerating processes, iron sulfides were changed to iron oxides and oxidized sulfur compounds (Slotta, 1974). The oxidation of sulfides increased the mobility of metals such as silver, lead and zinc from the sediments (Thomson, et al, 1973; Gordon, et al, 1972). The pH values of the mixture decreased as the results of organic oxidation and production of oxidized sulfur compounds. Therefore, the properties of the sediment-water mixture in the bioassay were different from those of the undisturbed deposited sediments.

Dissolved oxygen concentrations in the Harbor sediment-water mixture and fuller's earth-water mixture in the bioassay remained consistently above 5 mg/l, except in a few cases when the concentrations were slightly lower (Tables E-10 - E-37). Turbidity, suspended solids, dissolved solids, and pH varied according to sediment concentrations and among different stations. In order to compare these parameters between experiments with fuller's earth and the Harbor sediments, and also among the stations, the relationships between suspended solids and the other two parameters, turbidity, and pH, were considered.

The relationship between turbidity and suspended solid concentrations for fuller's earth is different from those observed for the Harbor sediment-water mixtures (Figure E-2). It is evident that the turbidity produced by a unit weight of suspended solids is much lower for fuller's earth-water

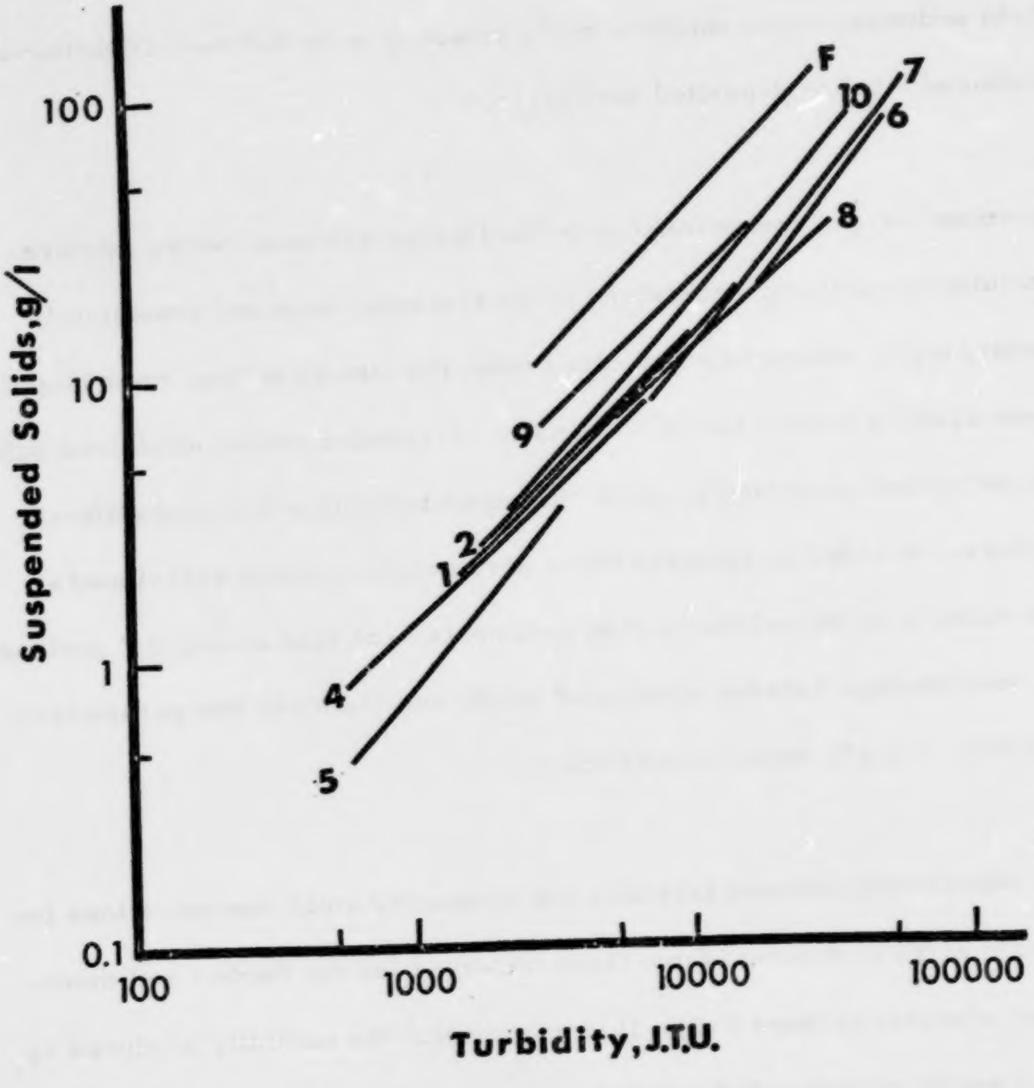


Figure E-2 Relationship between turbidity and suspended solid concentrations for fuller's earth-water mixture (F) and Baltimore Harbor sediment-water mixture (Stations 1-10).

mixture than that for Harbor sediment-water mixture. The difference among Harbor samples suggests that physical properties of suspended solids may differ between fuller's earth and the Harbor sediments, and among the sediments at the nine stations.

The relationship between pH values and suspended solid concentrations is shown in Figure E-3. For fuller's earth-water mixture, the pH value decreased very slightly as suspended solid concentration increased. The mixture always remained basic and its pH remained at 7.2 or higher. For the Harbor sediment-water mixture, the pH value decreased very rapidly as suspended solid concentration increased and reached the minimum at a concentration of about 20-30 g/l suspended solids for all stations. This fact might suggest that a factor related to suspended solids controlled the change of chemical equilibrium in the mixture, and this change was stabilized at this suspended solid concentration. If the release of toxic chemicals from the sediments into the mixture was involved in this chemical equilibrium, the dissociation of toxic chemicals from the sediments may have reached a maximum level at approximately 20-30 g/l. The concentration of suspended solids may, therefore, be one of the important factors controlling the release of toxic chemicals in the sediment-water mixture. There were differences in the rate of pH reduction and in the pH minimum among the stations. The stations

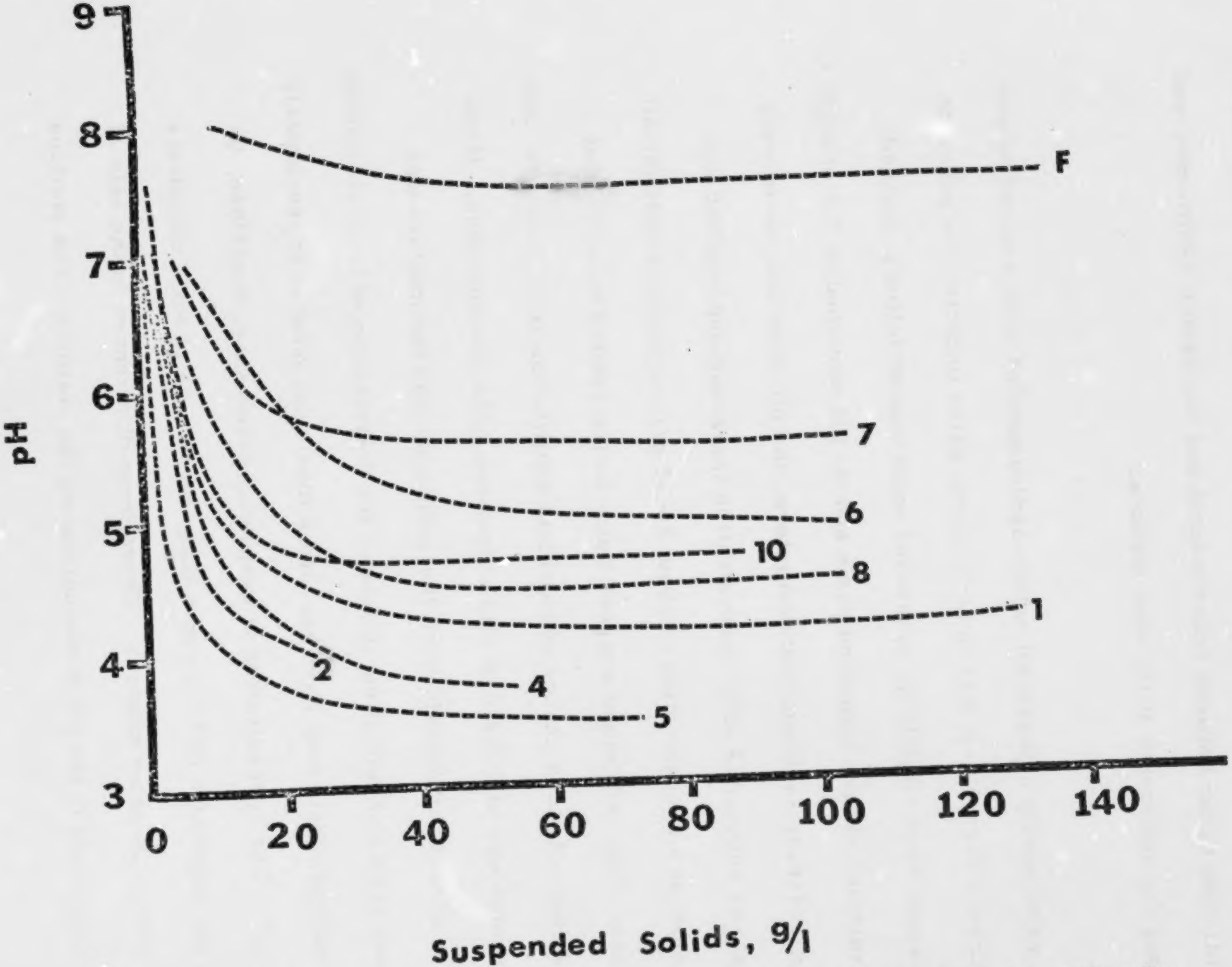


Figure E-3 Relationship between suspended solid concentrations and pH values for fuller's earth-water mixture (F) and sediment-water mixture of Baltimore Harbor (Stations 1-10, except 9).

which had the faster rates in pH reduction had the lower pH minima. The fastest rate in the pH reduction and the lowest value in pH minimum were at Station 5 (pH minimum about 3.5) followed in order by Stations 2, 4, 1, 8, 10, 6, and 7 (pH minimum about 4.7). The differences may be due to the difference in quality and/or quantity of chemicals, including toxic substances, released from the sediments.

The exception was Station 9. The sediment-water mixture was basic; and the pH values ranged between 8.9 to 9.3, higher than those of control water and of fuller's earth-water mixture (Table E-15). This is notably different from the other sediment water mixtures. The reason for the high pH values of Station 9 was not known. The sediment of this station was black like those from other stations, but contained many white clay-like lumps ranging in size from a millimeter to about 7.5 centimeters. When the sediment-water mixture was made, these lumps were broken into pieces and mixed well with the sediments. According to personal communication with Dr. Raymond Morgan, Chesapeake Biological Laboratory, these lumps may have been a kind of paint binder. It was suspected that these clay-like lumps might strongly affect the sediment-water mixture properties.

E.4.3 Time-Concentration Relationship

Median survival time is the length of the period between the time when the organisms are initially exposed to a test solution and the time when 50 percent mortality of the test population has occurred. This time was calculated from the equation describing the relationship between exposure time and probits (Finney, 1971) of cumulative mortality for each species at each concentration (Bliss, 1937). Then the relationships between median survival time and suspended solid concentrations were plotted for each species for fuller's earth and for the Harbor sediments at each station (Figure E-4). Generally, the median survival time increased as suspended solid concentration decreased, but the rate of the increase differed among the three species tested.

For spot, the rate of increase in median survival time as suspended solid concentration decreased was so fast that at all stations the median survival time approached infinity after 1440 minutes or 24 hours (Figure E-4). This suggests that spot will be able to survive indefinitely in the sediment-water mixture if they can survive for 24 hours. For mummichogs, the increase in the median survival time as suspended solid decreased was slower than that of spot (Figure E-5). It appears that most of the mummichogs will be able to survive indefinitely in the sediment-water mixture

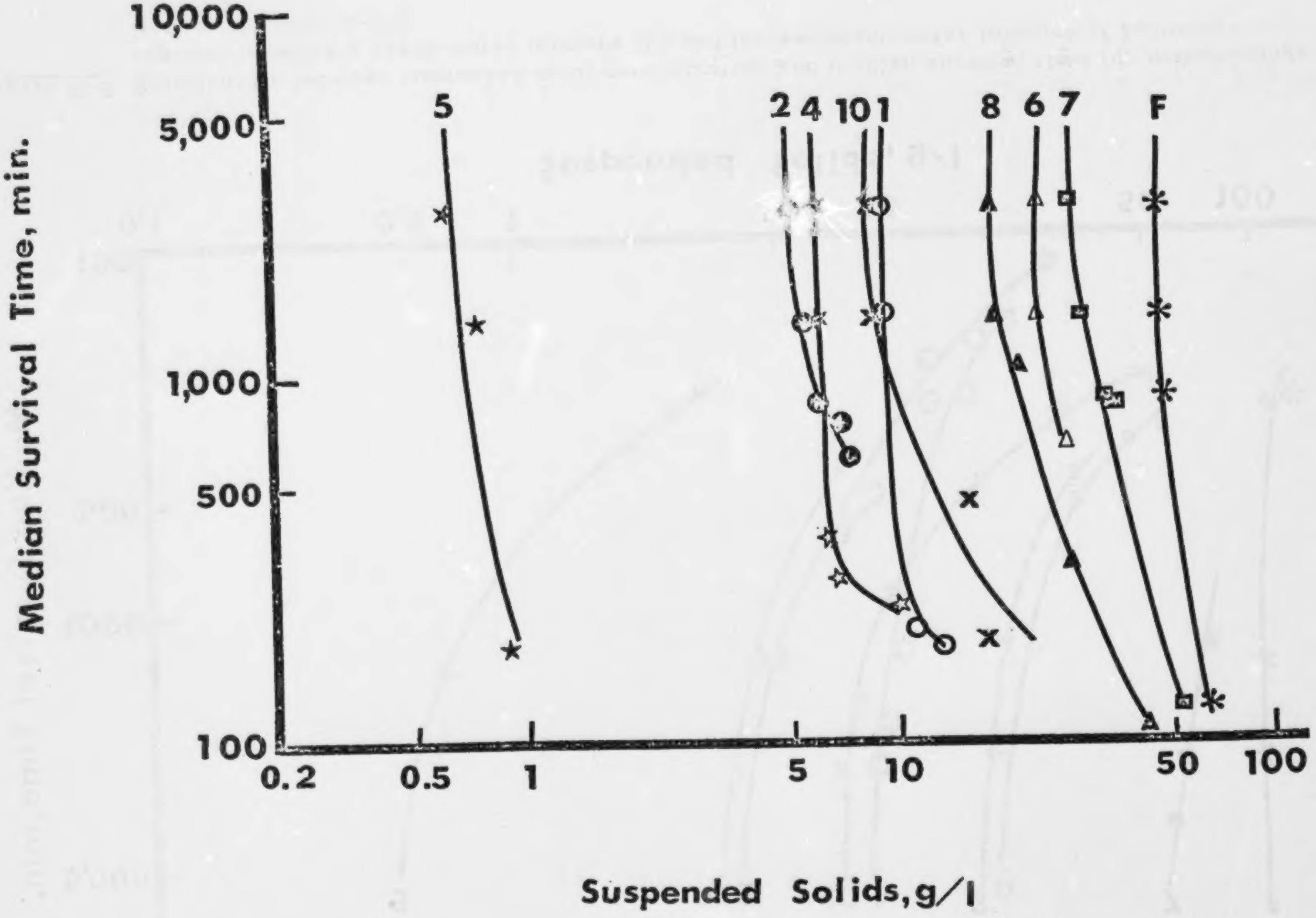


Figure E-4 Relationship between suspended solid concentrations and median survival time for spot exposed to fuller's earth-water mixture (F) and the sediment-water mixture of Baltimore Harbor (Stations 1-10).

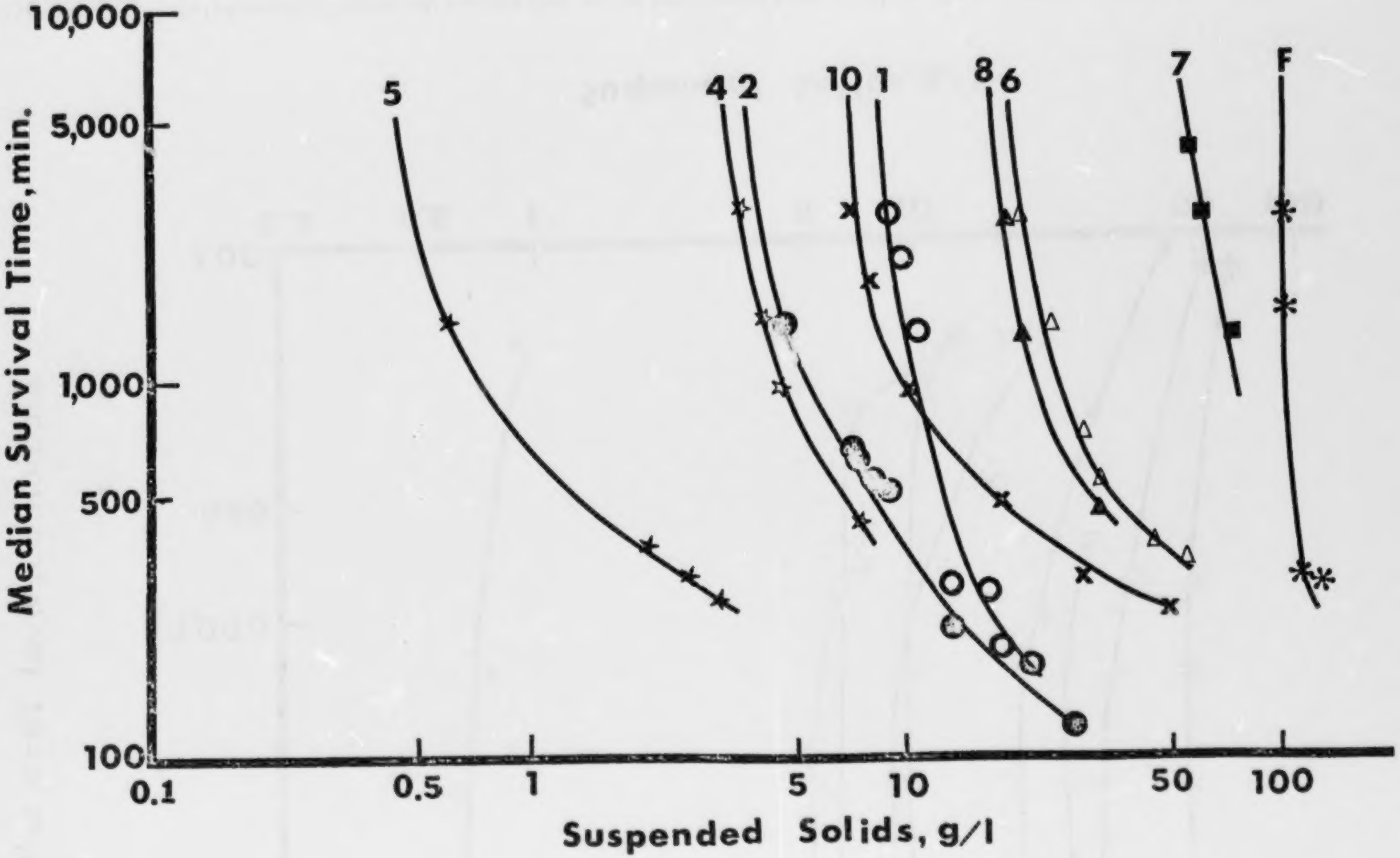


Figure E-5 Relationship between suspended solid concentration and median survival time for mummichogs exposed to fuller's earth-water mixture (F) and the sediment-water mixture of Baltimore Harbor (Stations 1-10).

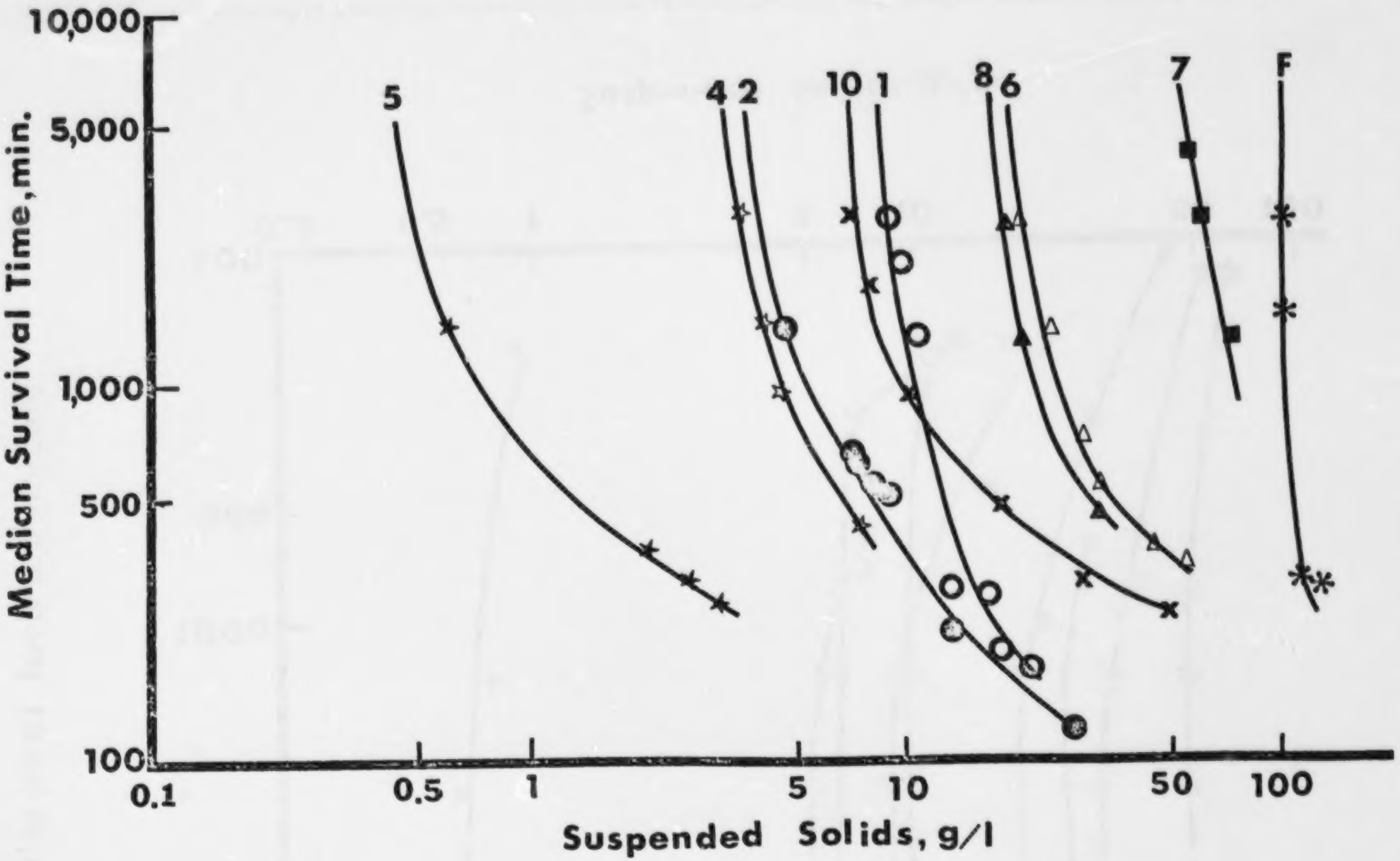


Figure E-5 Relationship between suspended solid concentration and median survival time for mummichogs exposed to fuller's earth-water mixture (F) and the sediment-water mixture of Baltimore Harbor (Stations 1-10).

if they can survive for 24 hours. Some of them will die after 24 hours. For soft-shell clams, the median survival time increased very slowly as suspended solid concentration decreased, a relationship very different from that for the two fish species tested (Figure E-6).

On the basis of median survival time, Station 5 was most toxic for all species, followed in decreasing order with small variations by Stations 2, 4, 10, 1, 8, 6, and 7. The fuller's earth-water mixture was distinctly less toxic than any sediment-water mixture from Baltimore Harbor.

E.4.4 Mortality-Concentration Relationship

The data on water quality and mortality of the three species of test organisms obtained in the bioassay are listed in Tables E-10 - E-37. For mummichogs and spot, the 24-hour and 48-hour percent mortality was transferred into probits and their relationship with suspended solid concentrations was established for each station. On the basis of the relationship equations, their 24-hour and 48-hour TLm values (median tolerant levels, the concentrations at which 50 percent of a test population was killed by the exposure for 24 hours and 48 hours respectively) for suspended solids were calculated for fuller's earth-water mixture and for the Harbor sediment-water mixture at eight stations. Because

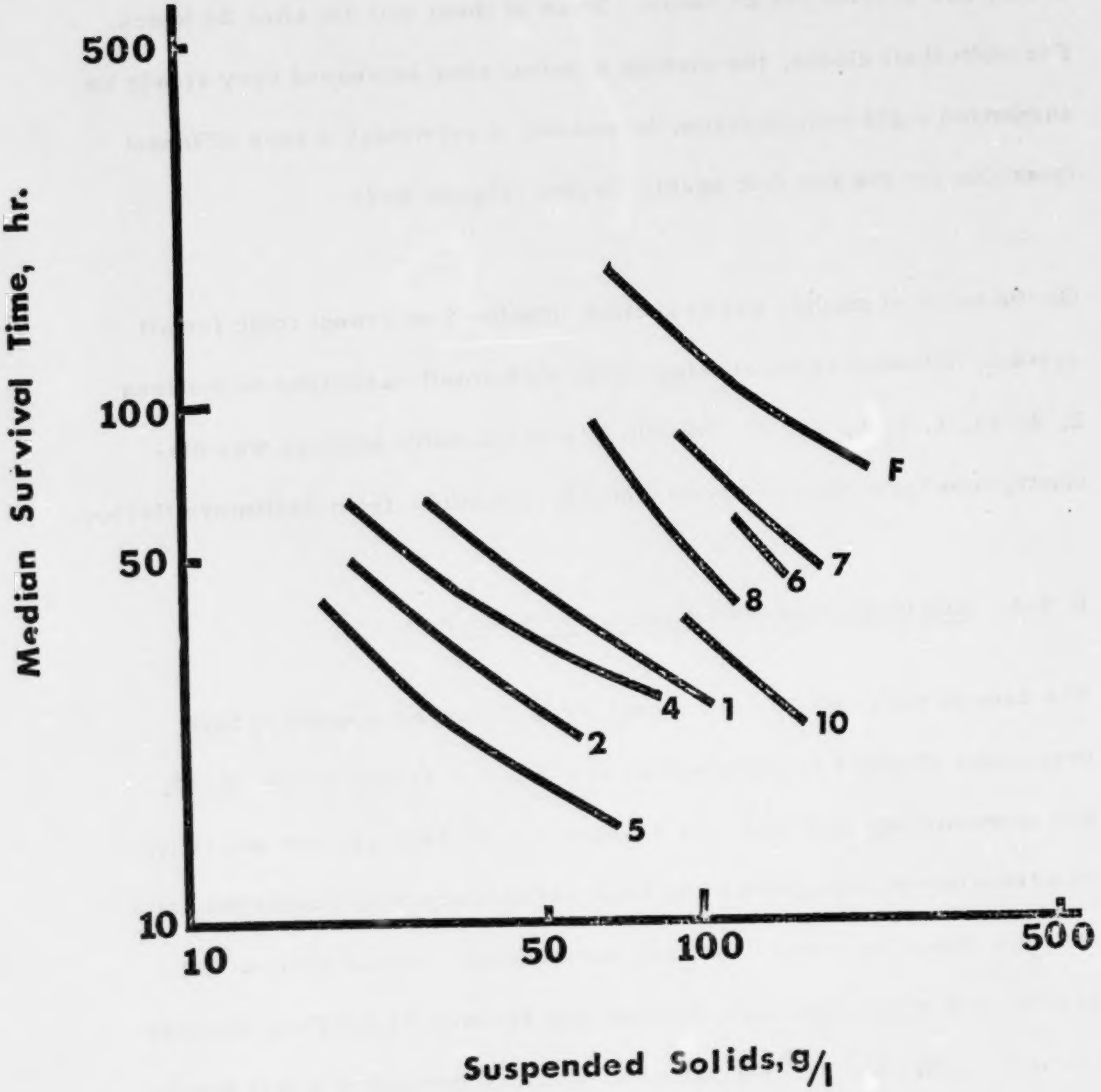


Figure E-6 Relationship between suspended solid concentration and median survival time for soft-shell clams exposed to fuller's earth-water mixture (F) and the sediment-water mixture of Baltimore Harbor (Stations 1-10).

of limitations in the capacity of the aerating and stirring systems and the high tolerance of the soft-shell clams to the sediments, it was impossible to make a sediment-water mixture concentrated enough to obtain 24-hour and 48-hour TLm for the clams in fuller's earth-water mixture and the Harbor sediment-water mixture at Stations 6, 7, and 8. Therefore, a 96-hour bioassay was conducted for them. The TLm values obtained for the soft-shell clams in this study were for exposure times of 24 hours and 48 hours for Stations 1, 2, 4, 5, and 10; 48 hours and 72 hours for Station 8; and 72 hours and 96 hours for Stations 6 and 7 and fuller's earth. The TLm values for suspended solids obtained for the three species of test organisms are shown in Table E-4.

When 24 hour TLm values and 48-hour TLm values for suspended solids were compared for each of the three species at each Harbor sediment station, it was found that there was a very strong positive correlation ($r = 0.99$) between the two values (Figure E-7). The results of analyses of convariance indicated that the slope of the regression line for soft-shell clams is similar to that of spot ($P > 0.20$), about 1, but different from that of mummichogs ($P > 0.005$). The elevation of the regression line for soft-shell clams is substantially different from that of both spot and mummichogs ($P > 0.005$). It is evident that the 24-hour TLm and 48-hour TLm increased proportionally for the three species of test organisms. In

TABLE E-4

TLm VALUES (SUSPENDED SOLIDS, 81e) FOR MUMMICHOGS, SPOT AND SOFT-SHELL CLAMS EXPOSED TO BALTIMORE HARBOR SEDIMENT-WATER AND FULLER'S EARTH-WATER MIXTURE

Station No.	Mummichogs		Spot		Soft-Shell Clams			
	24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.	72 hr.	96 hr.
1	11.79	9.72	9.36	9.31	160.98	136.82	-	-
2	4.93	4.21*	5.78	5.22	53.65	16.96	-	-
4	4.65	3.74	6.05	5.86*	84.56	57.88	-	-
5	0.63	0.58*	0.74	0.60	33.30	-	-	-
6	25.96	22.96	24.99	24.92	-	-	149.94	-
7	79.08	66.78	31.89	29.12	-	-	120.28	96.94
8	24.64	20.59	18.89	18.04	-	111.08	93.99	-
10	8.44	7.23	8.44	8.40	156.76	125.50	-	-
fuller's earth	107.48	103.29	50.61	50.61	-	-	188.58	137.20

* Values calculated from the formula in Figure 4-6.

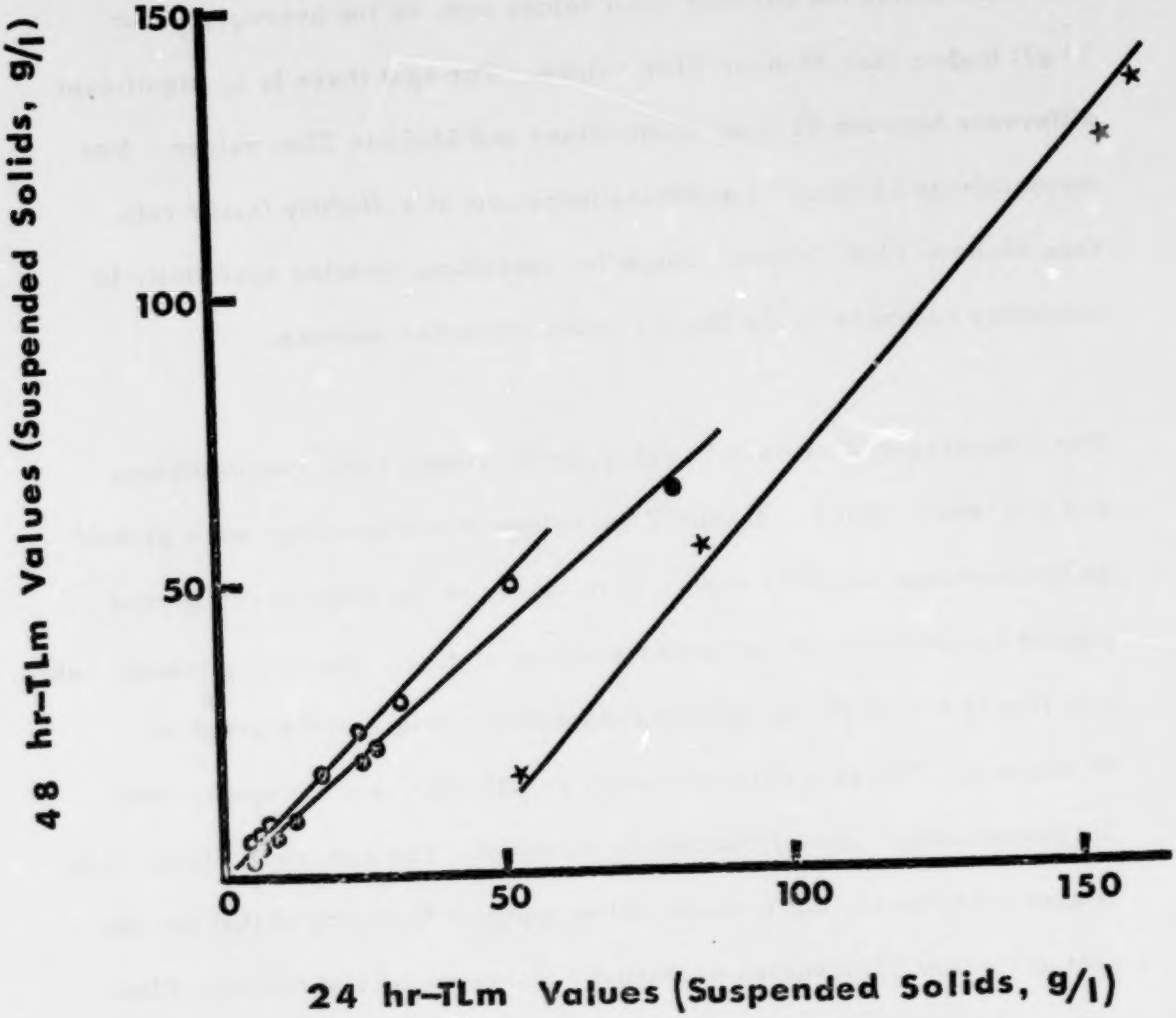


Figure E-7 Relationship between 24-hour TLm and 48-hour TLm values of mummichogs (solid circles; Y = 0.043 + 0.82 X, n = 7, r = 0.99), spot (open circles; Y = -0.0058 + 0.98 X, n = 7, r = 0.99), and soft-shell clams (stars; Y = -36.72 + 1.06 X, n = 4, r = 0.99) for suspended solids of Baltimore Harbor sediments.

other words, the two values are mutually convertible for the three species when exposed to Harbor sediments. The results also suggest that for soft-shell clams the 24-hour TLm values are, on the average, about 37 g/l higher than 48-hour TLm values. For spot there is no significant difference between 24-hour TLm values and 48-hour TLm values. For mummichogs 24-hour TLm values increased at a slightly faster rate than 48-hour TLm values. There is, therefore, species specificity in mortality response to the Harbor sediment-water mixture.

For comparison of sediment susceptibility among spot, mummichogs, and soft-shell clams, 24-hour TLm values of mummichogs were plotted on the abscissa and the 24-hour TLm values of the three species were plotted respectively on the ordinate in Figure E-8. The mummichogs' relation line is a straight line passing through the origin of the graph at 45 degrees. The spot relation line is curvilinear, and it departs from the mummichogs' line at Stations 6, 8, and 7. The soft-shell clams' line is also curvilinear, but it bends to the opposite direction of that for the spot at the low TLm values of Station 5 and especially at the high TLm values of Stations 6 and 8. It is evident that spot are more susceptible than mummichogs to fuller's earth and Harbor sediments at Station 7, for which the TLm values are high; whereas both species of fish have similar susceptibility to the Harbor sediments at Stations 1, 2, 3, 4,

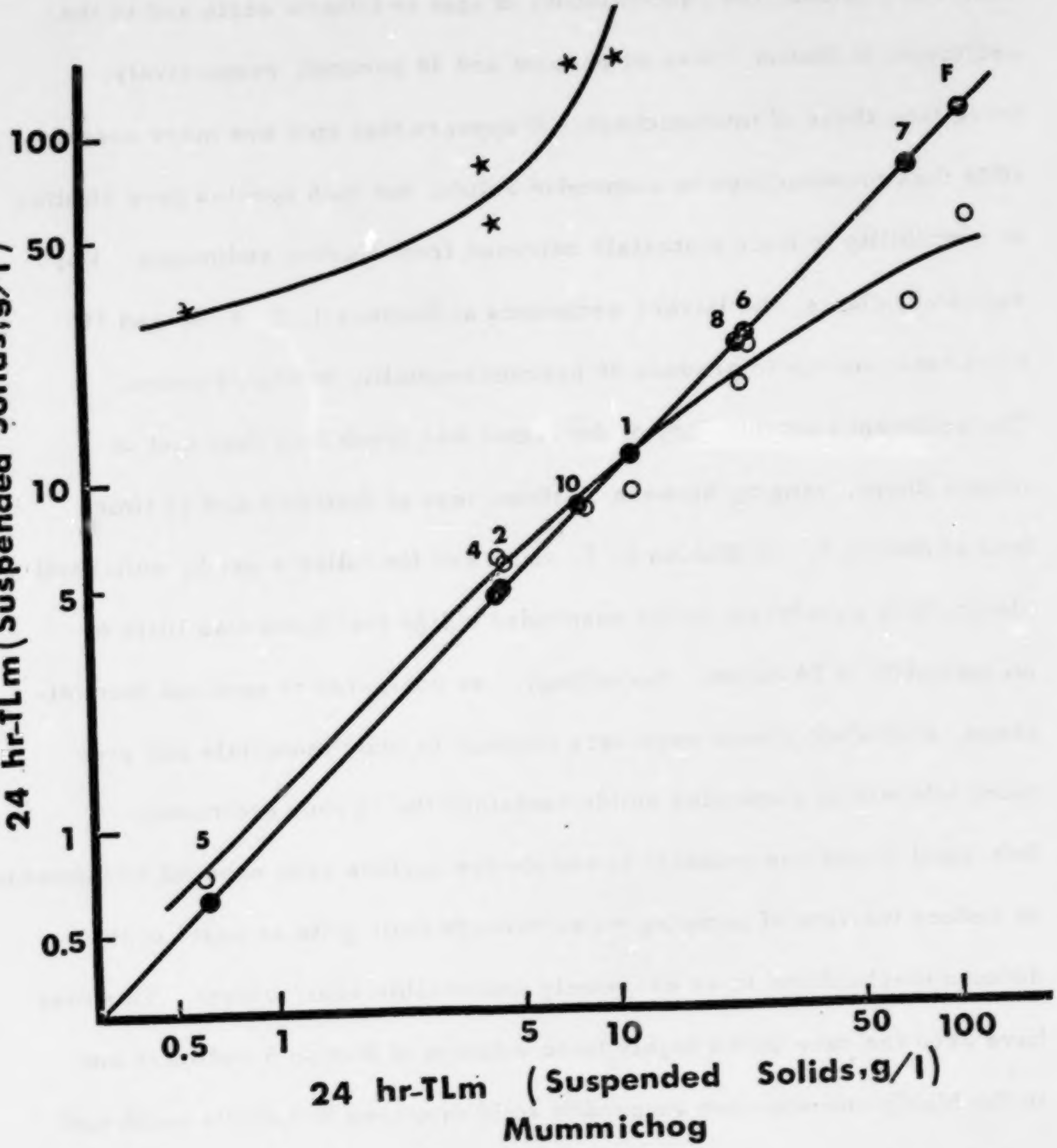


Figure E-8 Comparison of 24-hour TLm values among mummichogs (solid circles), spot (open circles), and soft-shell clams (stars) for fuller's earth (F) and Baltimore Harbor sediments (Stations 1-10).

5, 6, 8, and 10 where TLm values are low. On the basis of the 24-hour TLm values, the susceptibility of spot to fuller's earth and to the sediments at Station 7 was 42 percent and 48 percent, respectively, more than those of mummichogs. It appears that spot are more susceptible than mummichogs to suspended solids, but both species have similar susceptibility to toxic materials released from Harbor sediments. For soft-shell clams, the Harbor sediments at Stations 1, 2, 4, 5, and 10 were toxic enough to produce 50 percent mortality within 24 hours. The sediment susceptibility of the clams was much less than that of mummichogs, ranging between 53 times less at Station 5 and 13 times less at Station 2. At Station 6, 7, and 8 and for fuller's earth, soft-shell clams were so tolerant to the suspended solids that there was little or no mortality in 24 hours. Accordingly, as compared to spot and mummichogs, soft-shell clams were very tolerant to toxic materials and even more tolerant to suspended solids contained the Harbor sediments. Soft-shell clams can contract to reduce the surface area exposed to toxicants or reduce the rate of pumping water through their gills as parts of their defense mechanisms in an extremely unfavorable environment. This may have been the case in the highly toxic solution of Station 5 sediment and in the highly concentrated suspended solid mixtures of fuller's earth and of Stations 5, 8, and 7 sediments so that their survival time increased and the mortality rate was reduced.

It is interesting to note that the relation lines for spot and soft-shell clams increase their curvature and deviate farther from the mummichog relation line at about 20 g/l suspended solids (Figure E-8). This concentration coincides approximately to that of the sediment-water mixture at which pH values approach the minimum (Figure E-3). This evidence further supports the possibility that the amount of toxicants released from the Harbor sediments into the mixture was proportional to the suspended solid concentration until the mixture reached about 20 g/l of suspended solids. At approximately this concentration, the chemical dissociation and content of toxic chemicals in the mixture may reach the maximum. With further increase in the sediments in the mixture, the toxic constituents of chemicals in the mixture might remain fairly constant, while the suspended solid concentration increases and becomes a more important factor for fish mortality.

E.5 DISCUSSION

E.5.1 Gross Toxicity of Baltimore Harbor Sediments

Because the 24-hour TLm values and 48-hour TLm values were mutually convertible and there was no important difference in the order of sediment susceptibility among the three species at eight stations, the mummichog 24-hour TLm value for suspended solids in this study was selected as the index of gross toxicity for Baltimore Harbor sediments. On the basis of this index, Station 5 was most toxic, followed in decreasing order by Stations 4, 2, 10, 1, 8, and 6; and Station 7 was the least toxic. This is the same order found in the study of the time-concentration relationship. The difference in gross toxicity between the two extreme cases at Station 5 and Station 7 was about 125 times in terms of 24-hour TLm. It is evident that a wide range exists in the gross toxicity of Harbor sediments among different locations. The fuller's earth-water mixture was about 18 percent less toxic than the sediment-water mixture from Station 7.

In 1970-1971, the Center for Environmental and Estuarine Studies (1974) conducted a comprehensive biological study of Baltimore Harbor, including benthic invertebrates, crabs, fish eggs and larvae, and adult fish. In the study of benthic invertebrates, 28 sampling stations were designed, and at each station four samples were collected with a van Veen grab in March, June, September, and December of 1970. In this study, the species diversity index of each sample was calculated using Margalef's formula, $d = \frac{S-1}{\text{Log } N}$, where S is the number of species and N is the total number of individuals (McErlean and Mihursky, 1968). The average index was obtained from the four samples for each station. Of these stations, Station 17 (18), 15, 3, 26, 23, 7, and 20 were either almost identical or near to the sediment stations 2, 4, 5, 6, 7, 8, and 10 of this study. When mummichog 24-hour TLm values for suspended solids were plotted against average species diversity indexes of the seven stations, it was found that there is a somewhat sigmoid relationship between the two values (Figure E-9). When Station 7 and Station 5, with exceptionally high and low toxicity, are not included in consideration, there is a generally linear relationship for the remaining five stations. According to this straight line relation formula in Figure E-9, the average species diversity indexes at 28 stations for benthic invertebrates could be converted into mummichog 24-hour TLm values for suspended solids. Using these mummichog 24-hour TLm values as the indexes of gross toxicity, the distribution of the sediment gross toxicity in Baltimore Harbor could be mapped on the basis of arbitrary limits (Figure E-10). According to the sediment gross toxicity, the Harbor sediment can be divided into four toxic zones: a highly toxic zone where mummichog 24-hour TLm

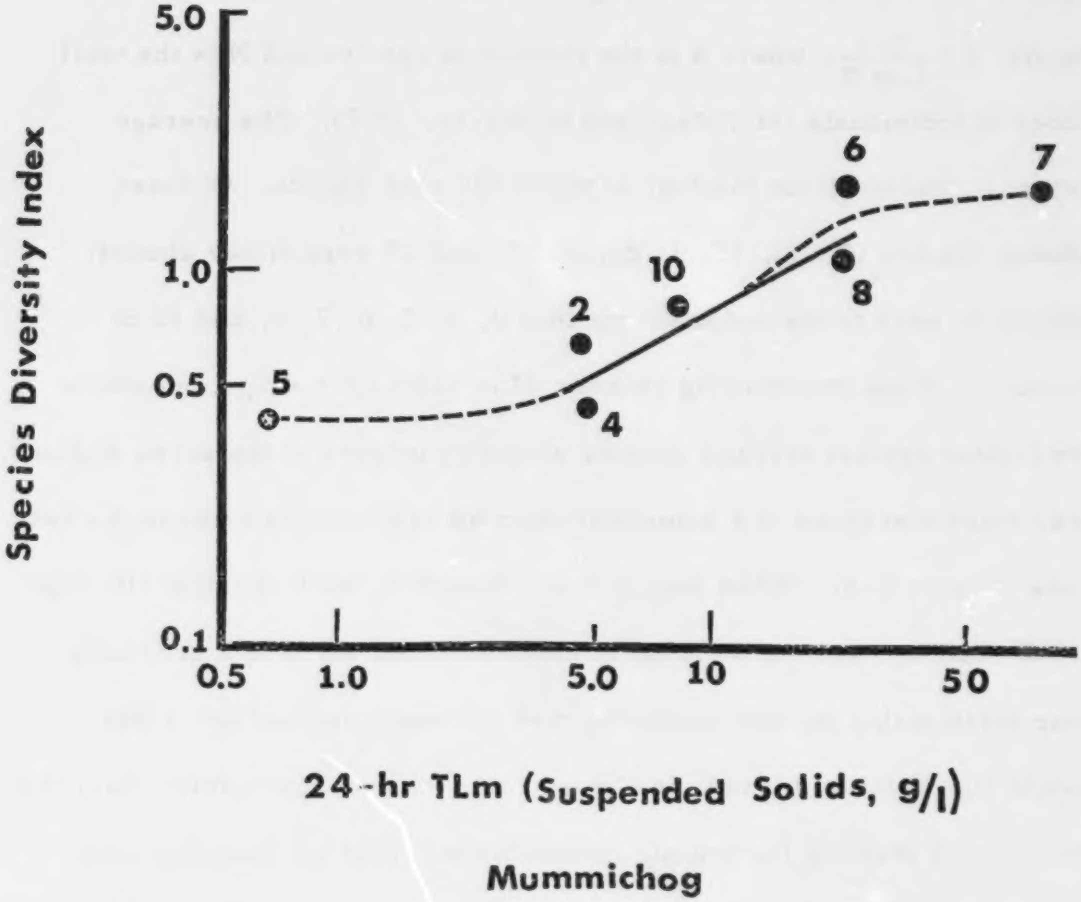


Figure E-9 Relationship between mummichog 24-hour TLm values for suspended solids and species diversity indexes of benthic invertebrates at seven stations in Baltimore Harbor. The regression equation of solid line is $\text{Log}_{10}Y = -0.5678 + 0.4782\ \text{Log}_{10}X$ ($n = 5$, $r = 0.89$).

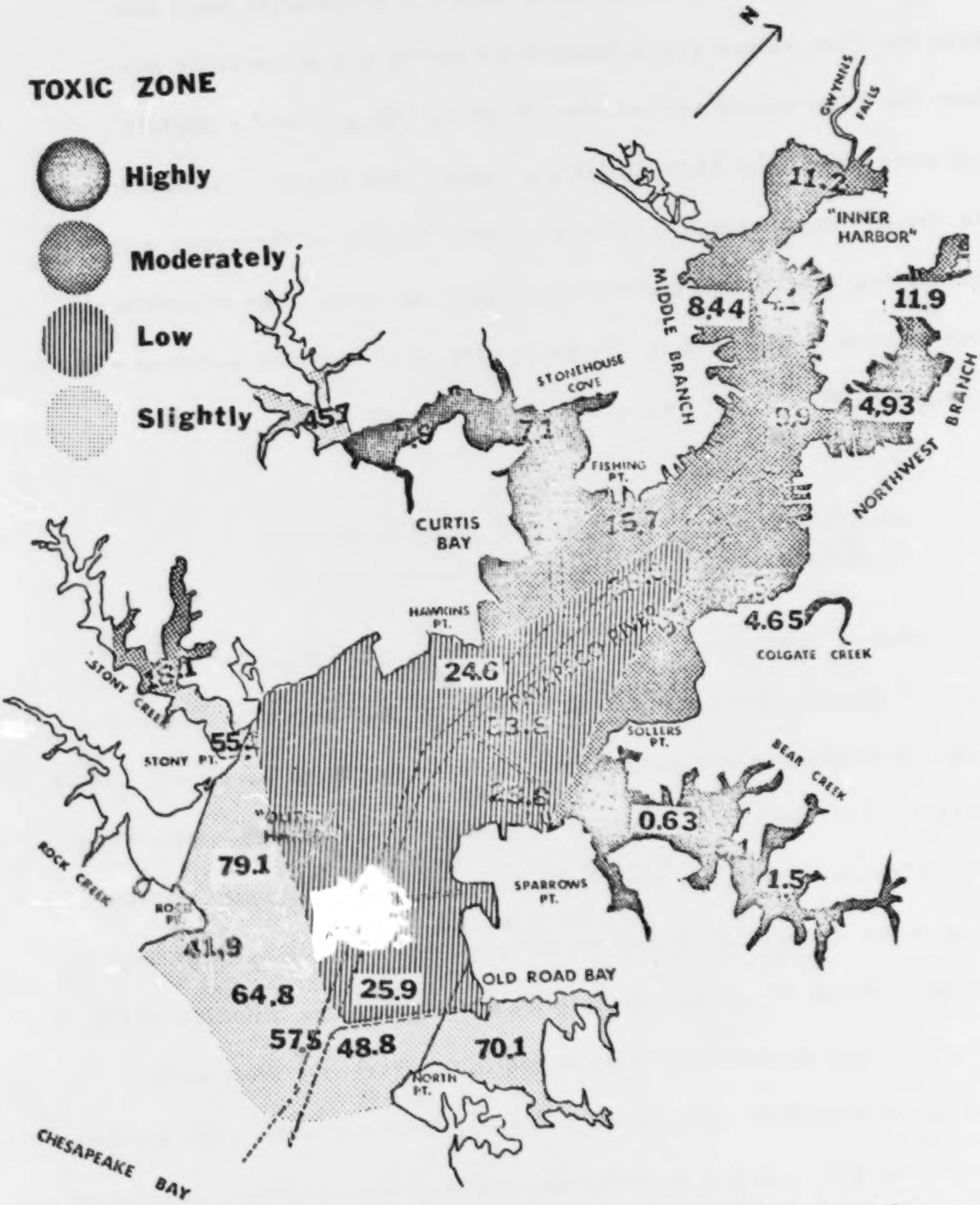

TOXIC ZONE
Highly
Moderately
Low
Slightly
N
GWYNNS FALLS
11.2
"INNER HARBOR"
MIDDLE BRANCH
8.44
11.9
STONEHOUSE COVE
45.7
7.1
4.93
NORTHWEST BRANCH
FISHING PT.
15.7
CURTIS BAY
HAWKINS PT.
24.6
4.65
COLGATE CREEK
STONY CREEK
55
STONY PT.
SOLLERS PT.
BEAR CREEK
0.63
79.1
SPARROWS PT.
1.5
ROCK CREEK
ROCK PT.
41.9
64.8
25.9
OLD ROAD BAY
57.5
48.8
70.1
NORTH PT.
CHESAPEAKE BAY

Figure E-10 Distribution of toxic zones and mummichog 24-hour TLm values for suspended solids in Baltimore Harbor (numbers in squares, real values obtained from the bioassay; numbers not in square obtained from conversion of species diversity indexes of benthic invertebrates).

values are less than 8 g/l suspended solids; a moderately toxic zone where the TLm values are between 8 g/l and 20 g/l; a low toxic zone where the TLm values are between 20 g/l and 40 g/l, and a slightly toxic zone where the TLm values are higher than 40 g/l. This zoning, with obvious imprecision, provides a useful display of the areas with greatest degradation and permits an estimation of the area of sediment which must be considered in efforts to correct or improve sediments of various toxicities in Baltimore Harbor (Figure E-10).

E.5.2 Relationship Between Biota and Sediment Toxicity in Baltimore Harbor

Thirty species of benthic invertebrates belonging to six phyla were found in Baltimore Harbor in the 1970 study by the Center for Environmental and Estuarine Studies (1975). The distribution of species diversity indexes at 28 stations in the Harbor is shown in Figure E-11. The index decreased from the slightly toxic zone to the highly toxic zone and was related to the distribution of sediment toxicity as noted in establishing the zones. Of the six phyla, Arthropoda, Mollusca, and Annelida were dominant groups of benthic invertebrates in the Harbor. They were almost equal in number of species in the slightly toxic zone. The number of species in Mollusca and Arthropoda, particularly the latter, decreased at the stations where sediment toxicity increased. In the highly toxic

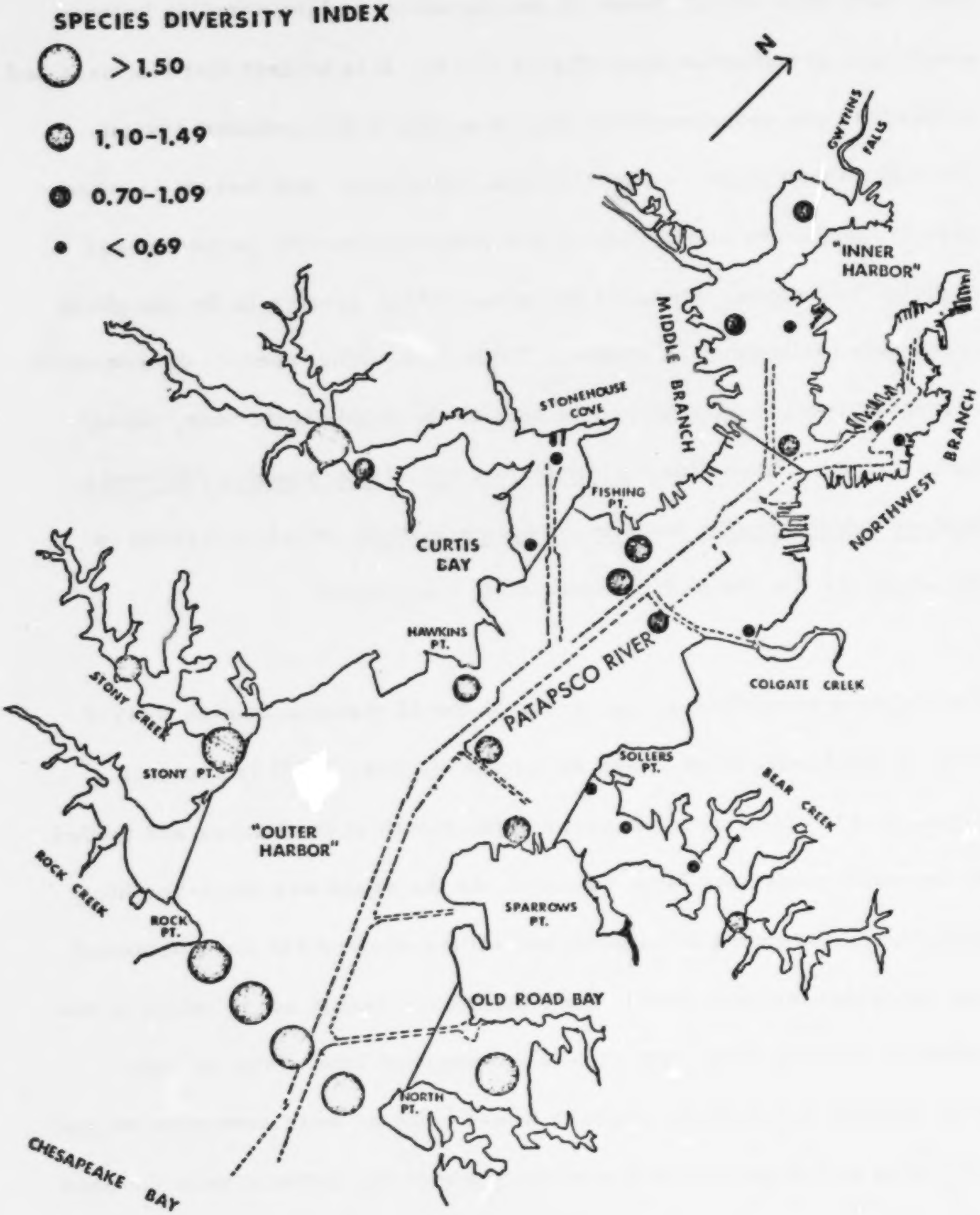

SPECIES DIVERSITY INDEX
>1.50
1.10-1.49
0.70-1.09
< 0.69
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
NORTHWEST BRANCH
STONEHOUSE COVE
FISHING PT.
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
"OUTER HARBOR"
SOLLERS PT.
BEAR CREEK
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-11 Distribution of species diversity indexes for benthic macro-invertebrate community in Baltimore Harbor (based on data from H. T. Pfitzenmeyer, Center for Environmental and Estuarine Studies, 1975).

zone, they were either absent or nearly absent, while Annelida became a dominant group in the zone (Figure E-12). It is evident that Mollusca and Arthropoda are more sensitive than Annelida to the sediment toxicity. The other three phyla -- Coelenterata, Nemertea, and Insecta -- were rare in the Harbor and limited in the sediments mostly in the low and slightly toxic zones. Relative abundance of the species in the six phyla in the four toxic zones is shown in Table E-5. Most species decreased in abundance from the slightly toxic zone to the highly toxic zone, except some species of Annelida: *Limnodrilus sp.*, *Heteromastus filiformis*, *Scolecolepides viridis*, and *Streblospio benedicti*, which increased in abundance in the low and/or moderately toxic zones.

The relative abundance of blue crabs at the 12 stations studied in 1970 (Center for Environmental and Estuarine Studies, 1975) is shown in Figure E-13. They were abundant at the mouth of the Harbor and tended to decrease toward the Inner Harbor. As the crabs are semi-benthic organisms, according to Lippson and Miller (Center for Environmental and Estuarine Studies, 1975), their abundance seems not to relate to the sediment toxicity alone, but also to the physical type of the bottom. They were abundant at the stations where bottoms were composed of mud and rocks and were rare at the stations where the bottoms were covered with oil and grease-like substance.

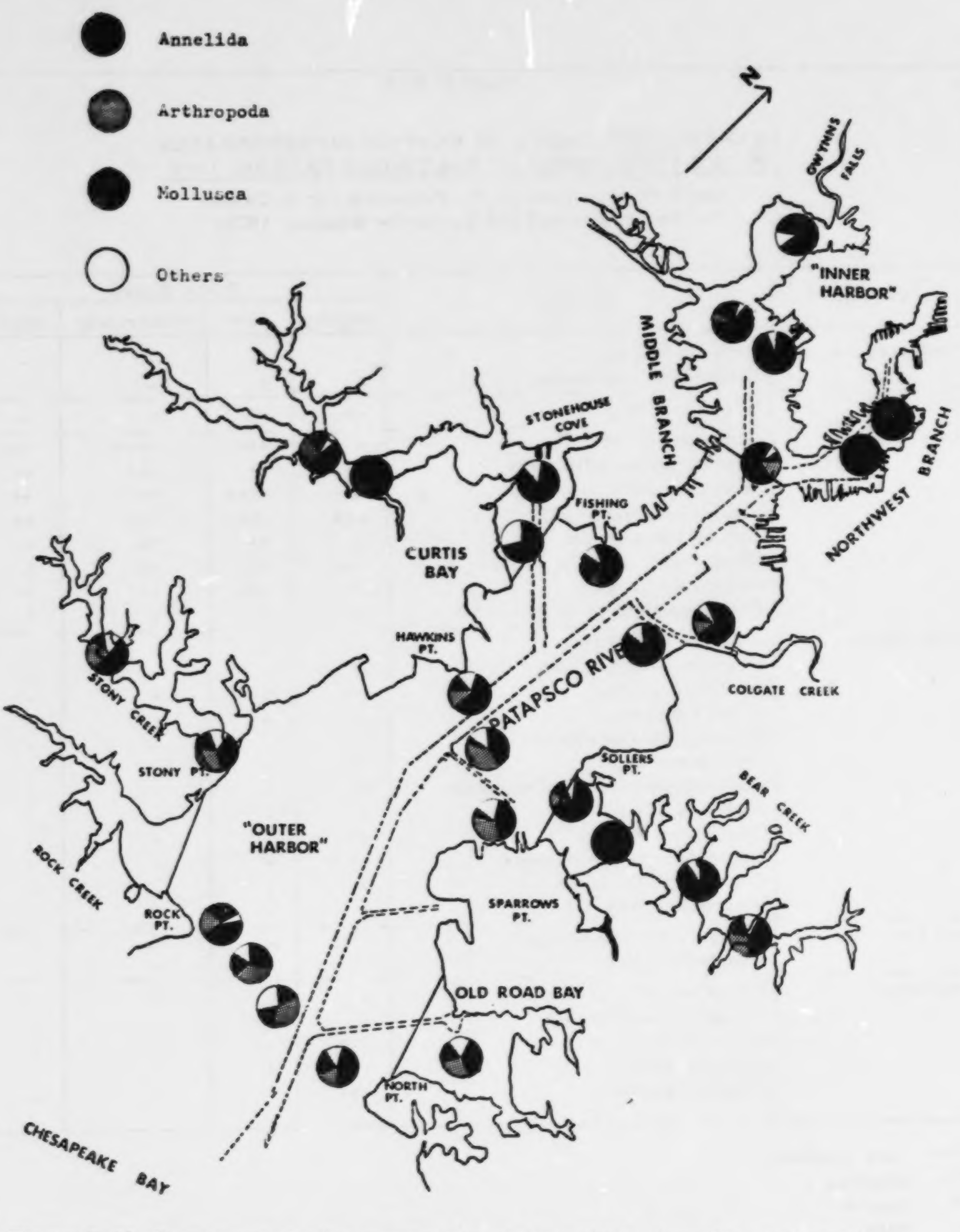

Annelida
Arthropoda
Mollusca
Others
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
NORTHWEST BRANCH
STONEHOUSE COVE
FISHING PT.
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
"OUTER HARBOR"
SOLLERS PT.
BEAR CREEK
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-12 Percentage species composition of three phyla, Annelida, Arthropoda, and Mollusca in Baltimore Harbor (Based on data from H. T. Pfitzenmeyer, Center for Environmental and Estuarine Studies, 1975).

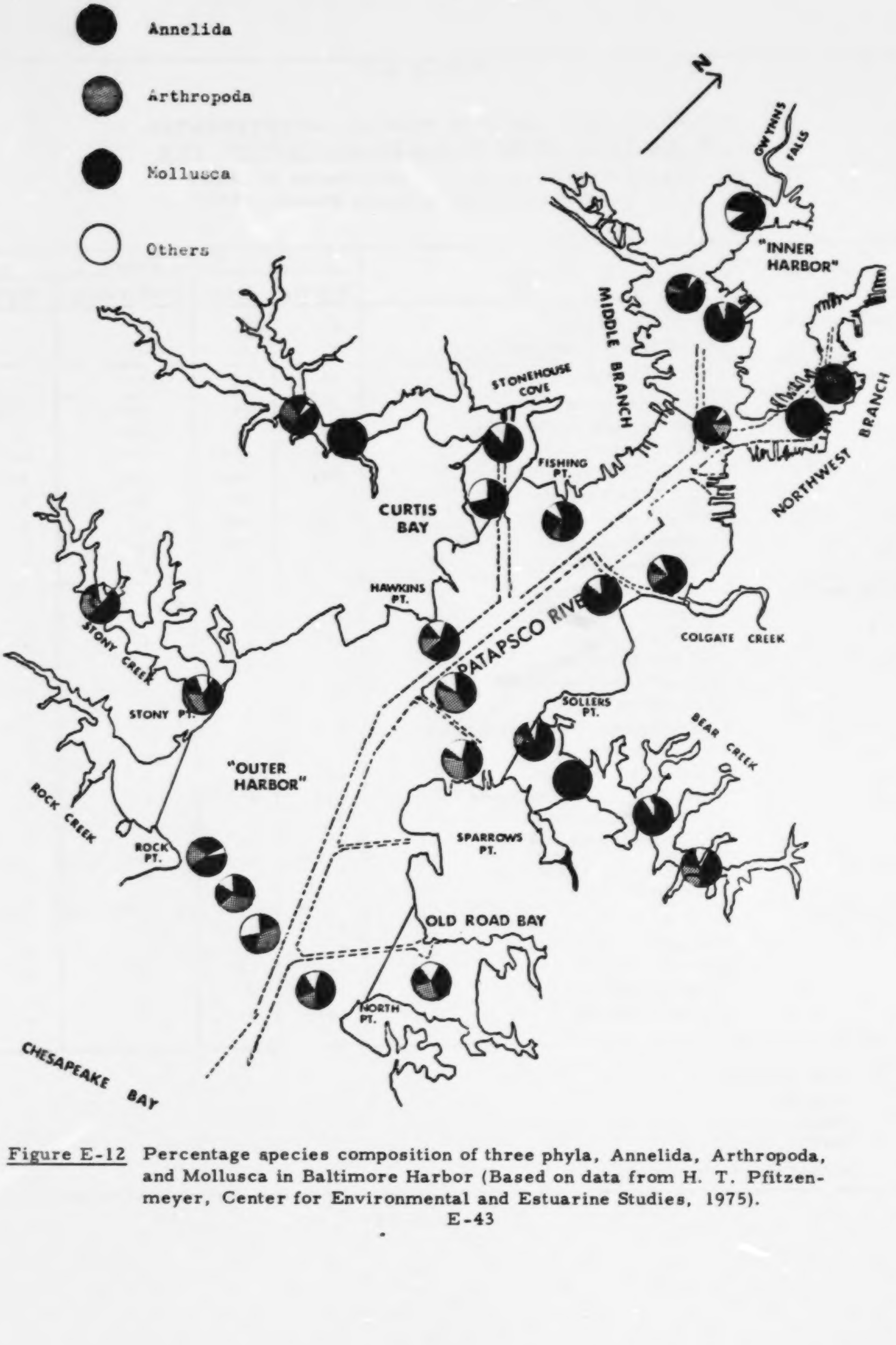

Annelida
Arthropoda
Mollusca
Others
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
NORTHWEST BRANCH
STONEHOUSE COVE
FISHING PT.
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
"OUTER HARBOR"
SOLLERS PT.
BEAR CREEK
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-12 Percentage species composition of three phyla, Annelida, Arthropoda, and Mollusca in Baltimore Harbor (Based on data from H. T. Pfitzenmeyer, Center for Environmental and Estuarine Studies, 1975).

TABLE E-5

RELATIVE ABUNDANCE OF BENTHIC INVERTEBRATES IN THE TOXIC ZONES OF BALTIMORE HARBOR, 1970

(Based on data from H. T. Pfitzenmeyer in Center for Environmental and Estuarine Studies, 1975)

Phylum	Species	Toxic Zones			
		Slightly	Low	Moderately	Highly
Coelenterata	Fagesia lineata	+	+	-	-
	Diadumene leucolena	+	+	-	-
Nemertea	Micrura leidyi	++	++	+	-
Annelida	Limnodrilus sp.	+	+++	++++	+++
	Heteromastus filiformis	++	++	+++	++
	Scolecolepides viridis	+++	++++	+++	++
	Streldospio benedicti	+++	++++	+++	++
	Eteone heteropoda	+	++	++	+
	Nereis succinea	+++	+++	++	+
	Hypaniola grayi	++	+++	++	+
	Polydora ligni	-	+	+	+
Arthropeda	Balanus amphitrite	-	+	-	-
	Neomysis americana	+	-	-	-
	Cyathura polita	++	+	+	-
	Edotea triloba	+	-	-	-
	Monoculodes edwardsi	+	-	-	-
	Jammarus sp.	+	+	-	-
	Carinogammarus mucronatus	+	+	-	-
	Melita nitida	+	-	-	-
	Cymadusa compta	++	+	+	-
	Leptochierus plumulosus	++++	+	+	-
	Corophium lacustre	++	+	-	-
	Rithropanopeus harrisi	+	++	+	-
Insecta	Chironomus atlenuatus	+	-	-	-
	Procladius sp.	+	-	+	-
Mollusca	Brachiodonte recurvus	+	-	-	-
	Congeria leucophaeta	+	-	-	-
	Macoma balthica	+++	++	+++	+
	Macoma phenax	++	+	-	-
	Rangia cuneata	+++	+	-	-

++++	*Very Abundant*
+++	*Abundant*
++	*Common*
+	*Rare*
-	*Absent or nearly absent*

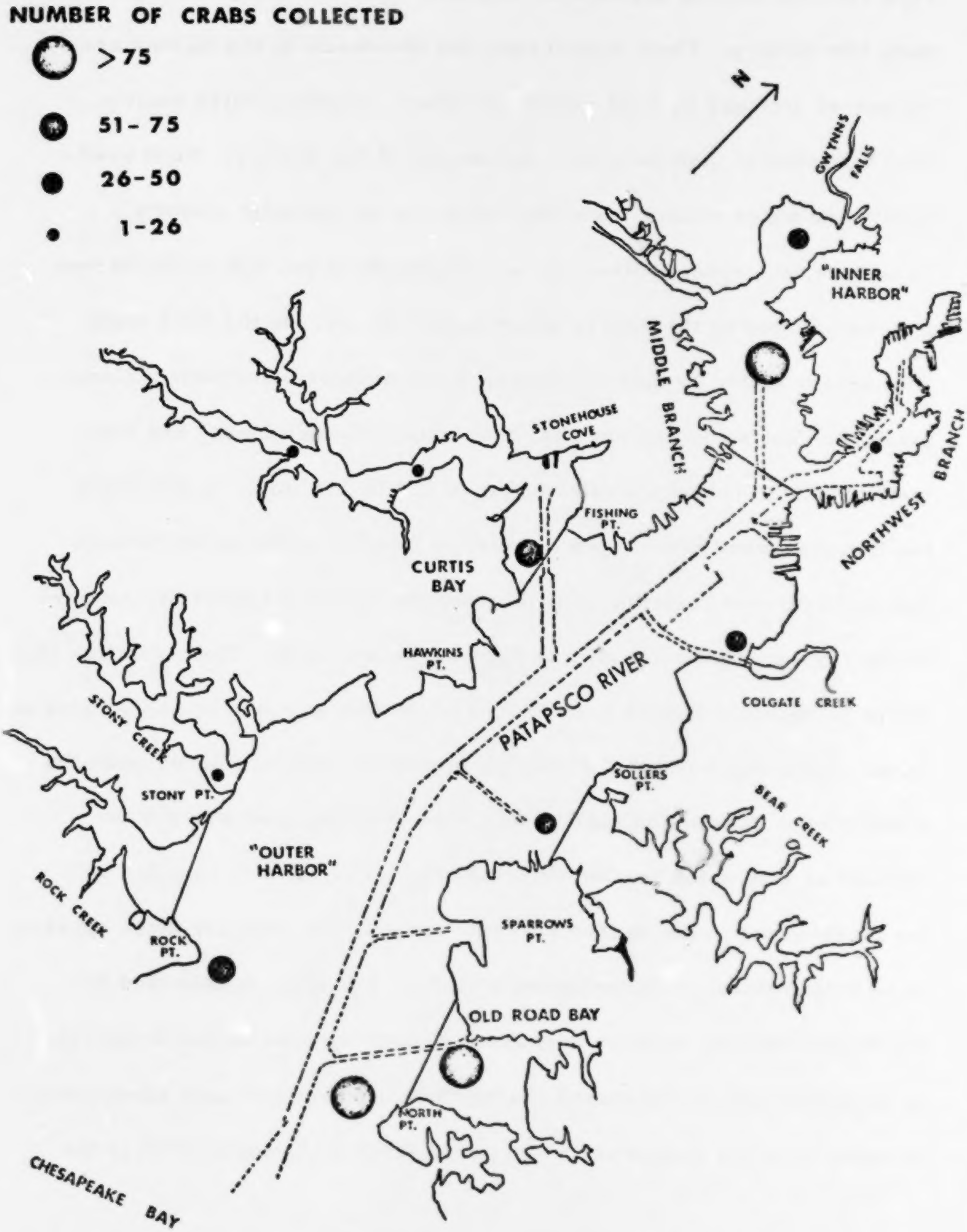

NUMBER OF CRABS COLLECTED
>75
51-75
26-50
1-26
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
STONEHOUSE COVE
FISHING PT.
NORTHWEST BRANCH
CURTIS BAY
HAWKINS PT.
COLGATE CREEK
PATAPSCO RIVER
STONY CREEK
STONY PT.
SOLLERS PT.
BEAR CREEK
"OUTER HARBOR"
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-13 Number of blue crabs collected in seven samples at 12 stations in Baltimore Harbor (Data from R. L. Lippson and R. W. Miller, Center for Environmental and Estuarine Studies, 1975).

Fish are free moving organisms, and their habitats change through their life history. Their occurrence and abundance in the Harbor are influenced strongly by tidal cycles, weather, seasons, water quality, food availability, fish behavior, and stages of life history. Food availability and water quality are often influenced by sediment toxicity. Therefore, the species diversity and abundance of the fish in the Harbor may be affected by the degree of sediment toxicity. In the 1970 study, fish were sampled by three methods: 50-foot shore seine with 1/2-inch mesh, 25-foot semi-balloon otter trawl with 1/2-inch mesh, and one-meter plankton net with mesh opening of 0.4 by 0.6 mm. In this study the fish data were rearranged in order to find the relationship between fish and sediment toxicity. The distribution of species diversity sampled by the three methods is shown in Figures E-14 - E-16. Their relative abundance is shown in Tables E-6 - E-8. For the fish sampled by shore seine and trawl, there was a trend of reduction in species diversity index from the slightly toxic zone to the highly toxic zone, but the trend was not so obvious as that of the benthic invertebrates. For the fish sampled by the plankton net in the Harbor channel, the species diversity index appears to be little related to the sediment toxicity. For the fish collected by the three methods, relative abundance of most species tended to decrease as sediment toxicity increased (Table E-6). Exceptions were silversides in water near the shores and white perch, rock fish, and alewife in the

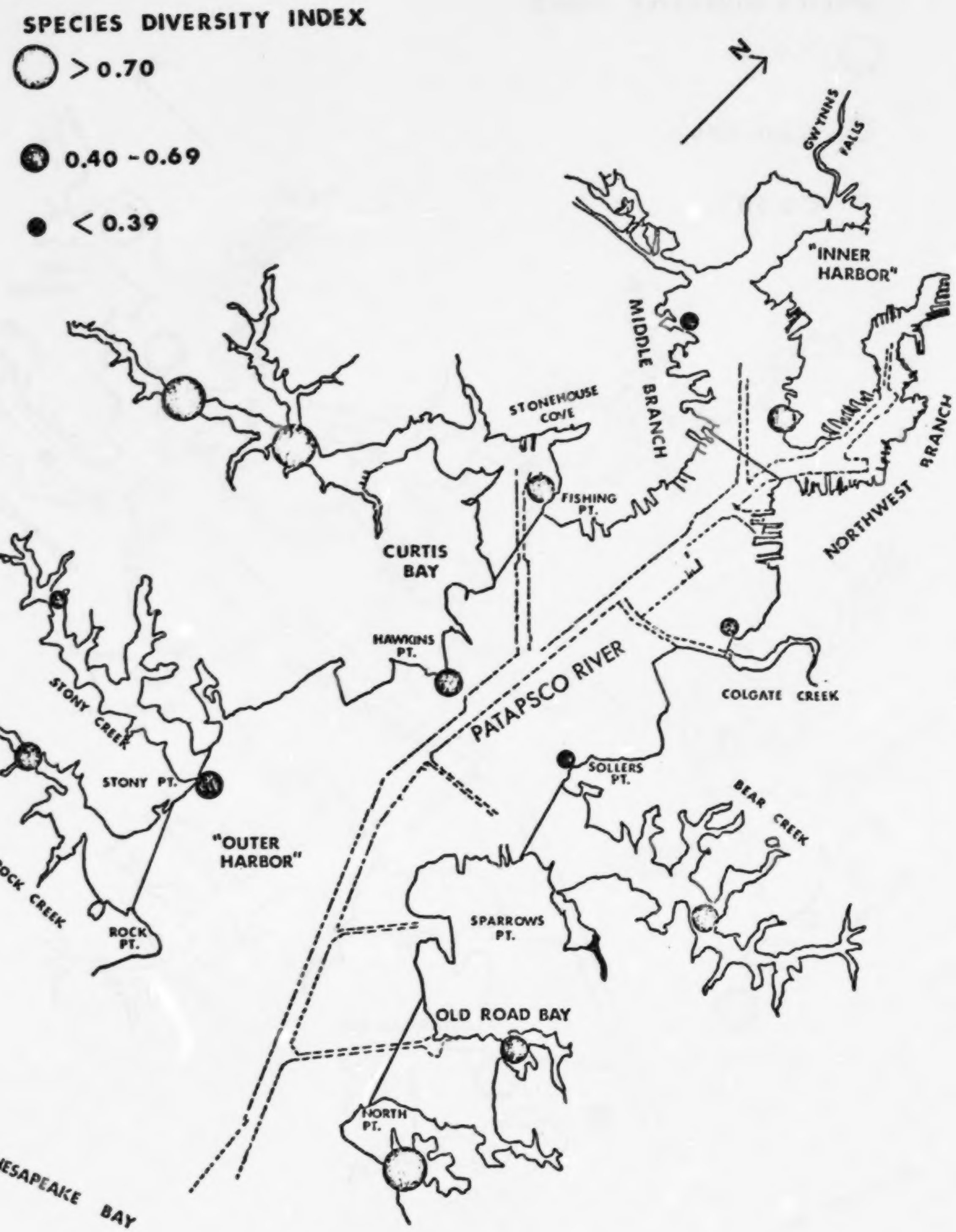

SPECIES DIVERSITY INDEX
○ > 0.70
● 0.40 - 0.69
● < 0.39
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
STONEHOUSE COVE
FISHING PT.
NORTHWEST BRANCH
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
SOLLERS PT.
BEAR CREEK
"OUTER HARBOR"
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-14 Distribution of species diversity indexes of fish sampled by a 50-foot shore seine in Baltimore Harbor (based on data from M. L. Wiley, Center for Environmental and Estuarine Studies, 1975).

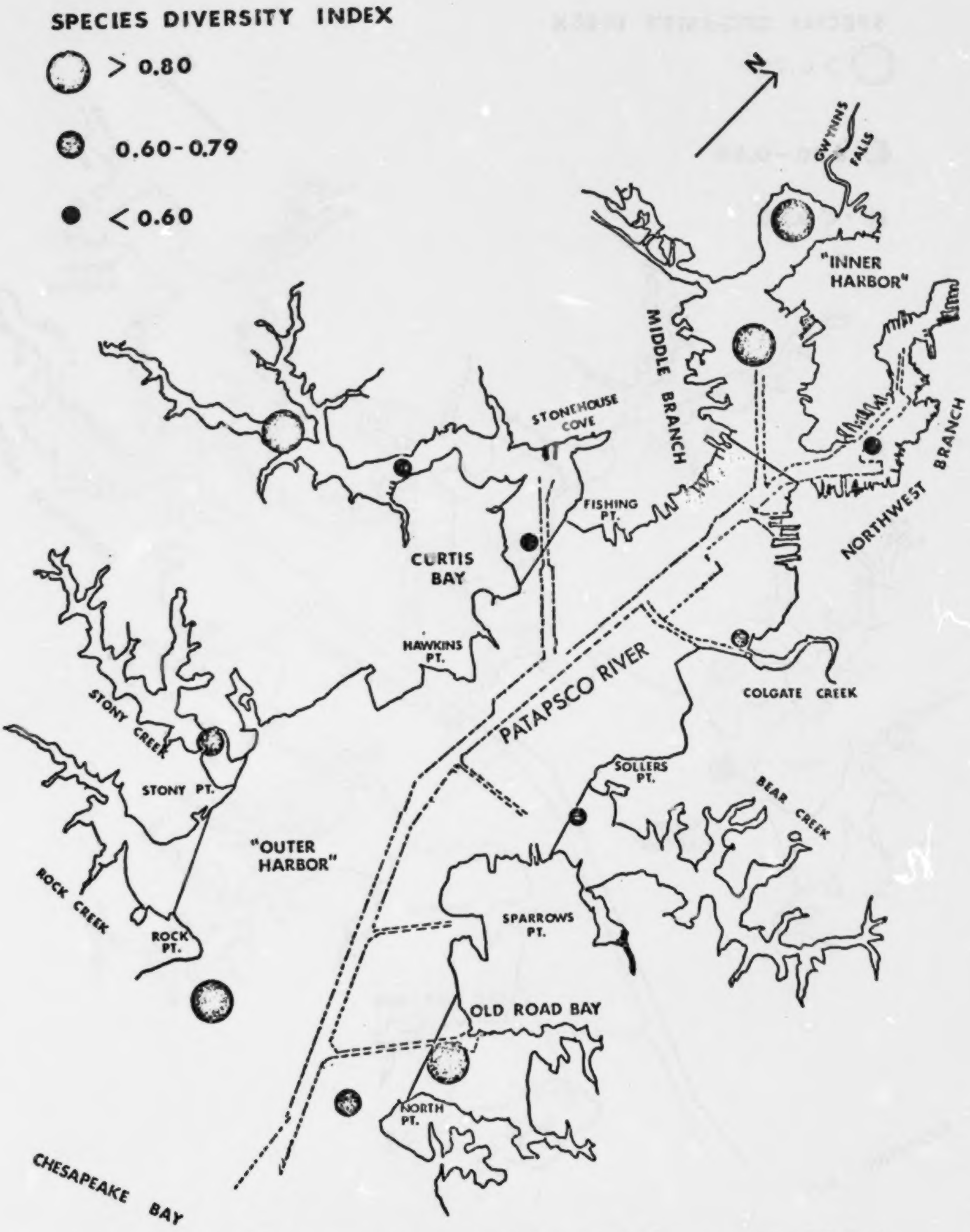

SPECIES DIVERSITY INDEX
○ > 0.80
◍ 0.60-0.79
● < 0.60
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
STONEHOUSE COVE
FISHING PT.
NORTHWEST BRANCH
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
SOLLERS PT.
BEAR CREEK
"OUTER HARBOR"
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-15 Distribution of species diversity indexes of fish sampled by a 25-foot semi-balloon otter trawl in Baltimore Harbor (based on data from W. L. Wiley, Center for Environmental and Estuarine Studies, 1975).

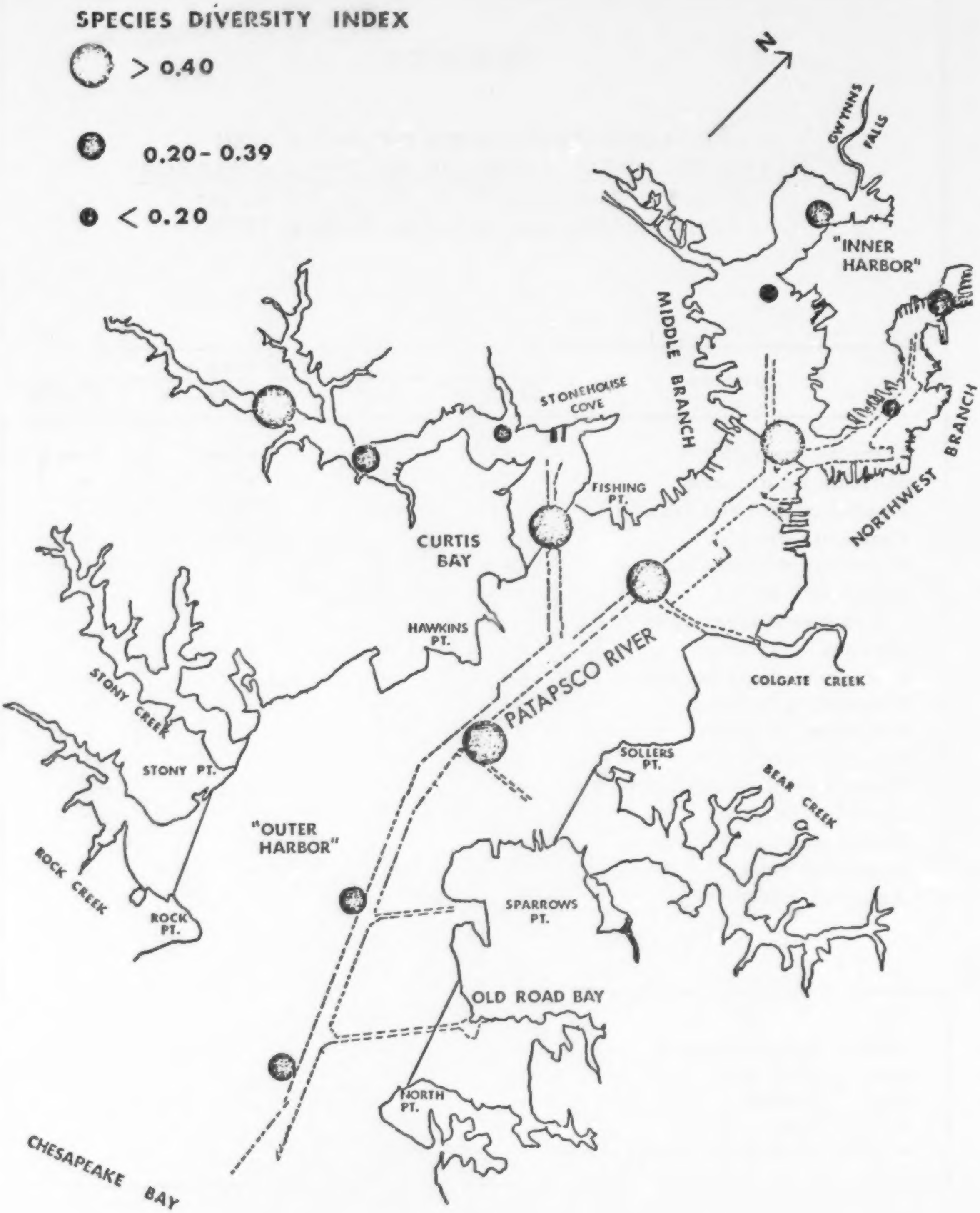

SPECIES DIVERSITY INDEX
> 0.40
0.20- 0.39
< 0.20
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
NORTHWEST BRANCH
STONEHOUSE COVE
FISHING PT.
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
SOLLERS PT.
BEAR CREEK
"OUTER HARBOR"
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-16 Distribution of species diversity indexes of fish sampled by a one-meter plankton net in Baltimore Harbor (based on data from M. L. Wiley, Center for Environmental and Estuarine Studies, 1975).

TABLE E-6

RELATIVE ABUNDANCE OF SHORE FISH IN THE POLLUTED ZONES OF BALTIMORE HARBOR

(Based on data from M. L. Wiley, Center for Environmental and Estuarine Studies, 1975)

Species	Toxic Zones			
	Slightly	Low	Moderately	Highly
Menidia menidia	+++	+++	++++	++++
Morone americana	+++	++	+	+
Fundulus heteroclitus	+++	++	++	+
Cyprinus carpio	++	-	++	+
Fundulus diaphanus	++	+	+	+
Alosa aestivalis	+	-	-	-
Alosa pseudoharengus	+	-	-	-
Morone saxatilis	+	+	+	-
Dorosoma cepidianum	+	-	-	-
Lepomis gibbosus	+	-	-	-
Fundulus majalis	+	-	-	-
Anchoa mitchilli	+	-	-	-
Hyporhamphus unifasciatus	+	-	-	-
Menidia berglina	+	-	-	-
Perca flavescens	+	-	-	-
Ictalurus catus	+	-	-	-
Anguilla rostrata	+	-	-	-

++++	*Very abundant*
+++	*Abundant*
++	*Common*
+	*Rare*
-	*Absent or nearly absent*

TABLE E-7

RELATIVE ABUNDANCE OF FISH COLLECTED BY A 12-FOOT SEMI-BALLOON OTTER TRAWL WITH A 1/2-INCH STRETCH MESH IN THE POLLUTED ZONES OF BALTIMORE HARBOR, APRIL TO DECEMBER 1970

(Based on data from M. L. Wiley, Center for Environmental and Estuarine Studies, 1975)

Species	Toxic Zones		
	Low	Moderately	Highly
Morone americana	++++	+++	+++
Morone saxatilis	+++	+++	+
Alosa pseudoharngus	+++	+++	++
Anchoa mitchilli	+++	+	+
Ictalurus catus	+++	+	+
Lepomis gibbosus	++	+	+
Perca flavescens	++	+	+
Alosa aestivalis	++	+	+
Anguilla rostrata	++	+	+
Menidia sp.	+	+	+
Trinectes maculatis	++	-	-
Pomatomus saltatrix	+	-	-
Cyanoscion regalis	+	-	-
Leiostomus xanthurus	+	-	-
Opsanus tau	+	-	-
Fundulus heteroclitus	-	+	-

++++	*Very abundant*
+++	*Abundant*
++	*Common*
+	*Rare*
-	*Absent or nearly absent*

TABLE E-8

RELATIVE ABUNDANCE OF FISH EGGS, FISH LARVA, AND JUVENILE FISH COLLECTED WITH 1-METER PLANKTON NET IN THE TOXIC ZONES OF BALTIMORE HARBOR, 1970

(Based on data from M. L. Wiley in Center for Environmental and Estuarine Studies, 1975)

Species	Toxic Zones			
	Slightly	Low	Moderately	Highly
	LARVA AND JUVENILES			
Alosa sp.	+++	+	++	+++
Anchoa mitchilli	+++	++	++	+
Menidia sp.	+	++	++	+
Gobiosoma bosii	+++	-	+	-
Morone americanus	++	+	+	+
Dorosoma cepediunum	+	-	-	-
Lepomis gibbosus	+	-	-	-
Brevoortia tyrannus	+	-	-	-
Fundulus sp.	+	-	-	-
Notropis hudsonius	+	-	-	-
Chasmodes bosquianus	+	-	-	-
	EGGS			
Anchoa mitchilli	+++	+++	-	+
Trinectus maculatus	++			

+++ *Abundant*
++ *Common*
+ *Rare*
- *Absent or nearly absent*

off-shore water. These fish were abundant in all zones and their distribution appears to be unrelated to sediment toxicity. Some bottom dwelling or bottom feeding species, such as winter flounders, Atlantic croaker, and hogchoker were absent in the Harbor.

The use of Baltimore Harbor as a spawning ground of fish was very limited. Only the eggs of Bay anchovy were found in both slightly and low toxic zones during the late spring and summer. The eggs of the hogchoker were found only in the Outer Harbor of the slightly toxic zone in July.

Bowman (1974) made biweekly samplings of phytoplankton at seven stations in Baltimore Harbor and two stations in Chesapeake Bay in the vicinity of the entrance to the Harbor. A total of 68 genera was found. The distribution of diversity indexes of genera calculated from Margalef's formula is shown in Figure E-17, and relative abundance of each genus is shown in Table E-9. The difference in genus diversity indexes was small. between 0.51 and 0.71 at the Harbor stations, lower than 0.85 at the Bay stations. The stations in higher toxic zones tended to have slightly lower diversity than those in less toxic zones. The total number of genera which occurred from March to August 1971 was 39 in the slightly toxic zone and low toxic zone, 52 in the moderately toxic zone, and

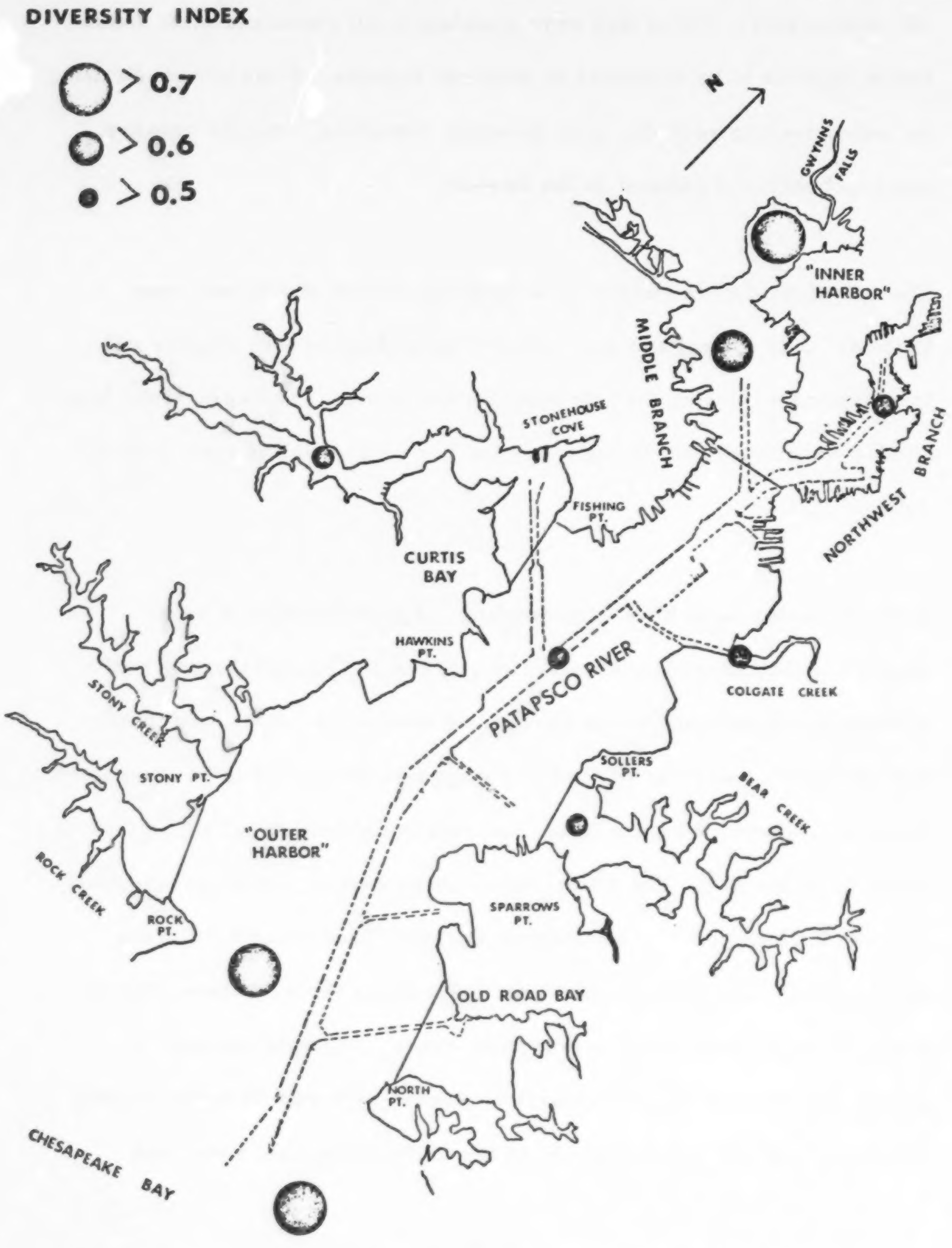

DIVERSITY INDEX
> 0.7
> 0.6
> 0.5
N
GWYNNS FALLS
"INNER HARBOR"
MIDDLE BRANCH
NORTHWEST BRANCH
STONEHOUSE COVE
FISHING PT.
CURTIS BAY
HAWKINS PT.
PATAPSCO RIVER
COLGATE CREEK
STONY CREEK
STONY PT.
SOLLERS PT.
BEAR CREEK
"OUTER HARBOR"
ROCK CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY

Figure E-17 Distribution of genus diversity indexes of phytoplankton in Baltimore Harbor (based on data from G. A. Brown, 1974).

TABLE E-9

RELATIVE ABUNDANCE OF PHYTOPLANKTON IN VARIOUS TOXIC ZONES OF BALTIMORE HARBOR, MARCH-AUGUST, 1971

(Based on data from G. A. Brown, 1974)

Genus	Toxic Zone			
	Slightly	Low	Moderately	Highly
Skeletonema	++++	++	+	+
Scenedesmus	+++	++	++	++
Pediastrum	+++	++	++	++
Exuviella	++	++	+	+
Chlamydomonas	++	-	+	+
Dictyosphaerium	++	+	-	-
Goniaulax	++	-	-	-
Oscillatoria	+	+	+	+
Ulothrix	+	+	-	-
Anabaena	+	-	+	-
Prorocentrum	+	-	-	-
Aphanizomenon	+	-	-	-
Ankistrodesmus	+	++	-	-
Coelastrum	+	-	-	-
Oocystis	+	-	-	-
Tetrustrum	+	-	-	-
Coscinodiscus	++++	++++	++++	++++
Fragilaria	++	+	+++	+
Melosira	++	++	+++	++
Nitzschia	++	++	+++	++
Chaetoceros	+	+++	+++	++
Navicula	+	+	++	+
Synedra	+	+	++	+
Cyclotella	++	++	++	++
Asterionella	++	+	++	+
Peridinium	+	-	+	+
Gleocystis	+	-	-	+
Staurastrim	-	-	++	+
Amphiprora	-	-	+	+
Meridion	-	-	+	+

Continued...

TABLE E-9 (Continued)

Genus	Toxic Zone			
	Slightly	Low	Moderately	Highly
Rhizosolenia	-	-	-	+
Cocconeis	-	+	-	-
Diatoma	-	-	+	-
Cymbella	-	-	-	-
Tabellaria	-	-	-	-
Cerataulina	-	-	-	-
Pleurosigma	-	-	-	-
Dinobryon	-	-	-	-
Tribonema	-	-	-	-
Thallasiosira	-	+	-	-
Microthamnion	-	-	-	-
Surirella	-	-	-	-
Microspora	-	-	-	-
Synura	-	-	-	-
Hormidium	-	-	-	-
Stigeoclonium	-	-	-	-
Ceratium	-	-	-	-
Crucigenia	-	-	-	-
Biddulphia	-	-	-	-
Amphora	-	-	+	-
Anacystis	-	-	-	-
Rhopalodia	-	-	-	-
Actinastrum	-	-	-	-
Diploneis	-	-	-	-
Anacystis	-	-	-	-
Botryococcus	-	-	-	-
Mallomonas	-	-	-	-
Kirchneiella	-	-	-	-
Phormidium	-	-	-	-
Stephanodiscus	-	-	-	-
Gymnodinium	-	-	-	-
Tetraedron	-	-	-	-
Eudorina	-	-	-	-
Eutreptia	-	-	-	-
Gleocapsa	-	-	-	-

++++ *Very Abundant*
+++ *Abundant*
++ *Common*
+ *Rare*
- *Absent or nearly absent*

49 in the highly toxic zone. The presence of a low diversity index by occurrence of high numbers of genera suggests an unstable phytoplankton community with the high turning over of genera at different times of the year in the highly toxic zone. The phytoplankton community in the Harbor was less diverse than that in the adjacent Chesapeake Bay, indicating the stressed condition of phytoplankton in the Harbor. Several genera, such as Coscinodiscus, Fragillaria, Melosira, Nitzchia, Schnedesmus, and Pediastrum, were abundant in all zones. Exuviella, Chlamydomonas, Dictyosphaerium and some other genera were common only in the slightly toxic zone, while Navicula, Chaetoceros and Synedra were commonly in the moderately and highly toxic zones.

E.5.3 Ecological Effects of In-Place Pollutants in Baltimore Harbor

According to the wide variation in gross toxicity among the sediments tested, the in-place pollutants in the Harbor sediments are clearly not homogeneously distributed but fairly patchy in distribution, perhaps because of their sources and local events. They seem not to be transported for long distances by water and Harbor activities. Except for extreme storm conditions, they appear unlikely to be transported in large quantities from the Inner Harbor to the Outer Harbor or from the Harbor to the Bay. The Harbor sediments have become a sink or trap for much of the pollutants produced by domestic and industrial activities of the City of Baltimore.

The present biotic structure and distribution in the Harbor resulted from the combined effects of pollutants in the water column, derived directly from the discharges of domestic and industrial wastes, and of pollutants accumulated in the Harbor sediments. The benthic invertebrates and bottom dwelling fish are in constant contact with the sediments and feed primarily on foods produced in or on them. They have been the organisms most seriously affected by toxic chemicals in the sediments. The pelagic organisms are influenced primarily by toxic chemicals in the water column, whose sources are direct domestic and industrial waste discharge, import from the Bay, and, to some degree, release from the bottom sediments.

The transfer of contaminants such as heavy metals, nutrients and pesticides across the sediment-water interface is complex and not yet fully understood. Morton (1976) reviewed the literature and identified several factors important to the process, such as sediment clay content, organic fraction, redox potential, pH, bacteria, sulfur cycle and iron cycle. The clay particles preferentially sorb heavier metallic ions (Reynolds, et al, 1973). Metals which form highly insoluble metal sulfides have little chance of leaving the sediments. Relatively soluble metal compounds might migrate up the sediment column until encountering an aerobic environment which may set the limit of their mobility if they are converted to insoluble oxide compounds. On the basis of solubility product constants for the sulfide compounds of metals, Pb, Cd, Ni, Hg, Ag, Cu, and Zn should remain essentially fixed in sediments having interstitial water with a sulfide ion activity of 10^{-9} moles/liter. Mn and Fe will be readily mobilized since MnS and FeS have high solubility (Thomson, et al, 1973). Accordingly, even though there is some transfer of contaminants from the sediments to the water column, the process will be very slow and ecological effects on the water column might be minor.

Two likely pathways by which toxicants enter the food chain in the water column in the estuary are from the sediments into rooted plants and ingestion of solid particles with sorbed toxicants by organisms (Wolfe, 1973). The in-place pollutants in Baltimore Harbor are indeed a problem, particularly for bottom dwelling organisms, but they exist as a nearly immobile reservoir. A different kind of biological threat is posed by domestic and industrial wastes which have been and are discharged to the Harbor not only to contaminate the Harbor water, but also to "enrich" pollutants in the bottom sediments. The input of these is still substantial (Maryland Environmental Service, 1974).

The flushing rate of the open fairway has been found to be relatively high (Stroupe, et al, 1961). It is suspected that if the domestic and industrial waste discharges were suspended, water quality of the water column in the Harbor would return to a nearly natural condition, and fish and other pelagic organisms would repopulate to form a healthy water column community in a short period of time. It would take a longer time for benthic communities to recover toward natural and healthy conditions, and these might never be reestablished over the more seriously polluted areas. If the in-place pollutants alone of the Harbor were cleaned up and domestic and industrial wastes were still discharged into the Harbor, water quality of the Harbor water column would remain contaminated as before; and pelagic biotic communities would remain unhealthy. The toxicants from the wastes in the water column would continue to be trapped by suspended solids and settle quickly to the bottom to form additional toxic sediments. Accordingly, the present in-place pollutants in Baltimore Harbor are of considerable concern, but they cannot be fully corrected except through simultaneous treatment and the prevention of further additions from domestic and industrial waste discharges.

Because of the presence of high concentrations of persistent pollutants, particularly heavy metals, in Baltimore Harbor sediments, concern exists about the possible danger of release of these pollutants into the water column and their concentration, cycling and magnification in the food web, so-called bioconcentration. American oysters, Crassostea virginica, are known to concentrate in ten weeks an amount as much as 50,000 times the lead, zinc, copper; 700 times the cadmium and about 500 times the chromium in the surrounding water (Shuster and Pringle, 1969). Fish are known to accumulate mercury as much as 3,000 times that in the surrounding water (Johnels and Westermark, 1969; Hannerz, 1968).

In the Upper Chesapeake Bay, this possible bioconcentration of heavy metals in oysters resulting from spoil disposal of Baltimore Harbor sediments into the Kent Island and other open Bay spoil areas caused concern in the late 1960's, and was studied in 1970 (Cronin, et al, 1974). The results of the study indicated that the heavy metal concentrations in the oysters were below "alert levels", and the uptake of metals by the oysters had no detected relationship to the concentration of the metals in surrounding water or on suspended sediments. Also, the concentration of metals in the oysters were, to a high probability, independent of distance from the bottom. Instead, uptake rates were related to growth rate and salinity or some factors coincident with it. It appears that the heavy metal concentration in the water column and in the bottom sediments did not cause a dangerous concentration in the oysters in the Chesapeake Bay and also were not factors at all in bioconcentration of the metals in oysters. Morgan (1972) exposed clams, *Macoma balthica*, *M. phenax*, and *Rangia cuneata*, in Baltimore Harbor water for eight weeks. It was found that concentrations of the heavy metals in clams were very minor, and in some instances there were no significant differences from those in the control. Morton (1974) concluded from his literature review that biological uptake and accumulation by aquatic organisms did not occur as might be expected in polluted areas. This has caused a controversy over the relative significance of bioconcentration. It is still impossible to predict if and to what extent bioconcentration will occur, because the potential release of toxicants across the sediment-water interface is complex and not well understood.

E.6 SUMMARY

In-place pollutants in Baltimore Harbor are patchy in distribution. Sediment from the most toxic station sampled was about 125 times as potent as that from the least toxic. Among the pollutants determined, hexane extracts correlated significantly with bulk concentrations of PCB, Pb, Cr, Zn, and Cd, but the sediment moisture had no relationship to heavy metal contents.

For the three species of estuarine organisms, spot, mummichogs, and soft-shell clams, 24-hour TLm and 48-hour TLm values for suspended solids correlated strongly and, thus, these two values for each species were mutually convertible.

Spot were more susceptible to suspended solids than mummichogs, but both species had similar susceptibility to toxic chemicals released from the Harbor sediments. As compared to these two fish species, soft-shell clams were very tolerant to toxic materials and even more tolerant to suspended solids.

Based on mummichog 24-hour TLm values for suspended solids used as the index of sediment gross toxicity, the Baltimore Harbor sediments may be divided into four toxic zones: a highly toxic zone, with TLm values less than 8 g/l; a moderately toxic zone, with TLm values between 8 g/l and 20 g/l; a low toxic zone, with TLm values between 20 g/l and 40 g/l; and a slightly toxic zone, with TLm values higher than 40 g/l.

The effects of sediment toxicity on benthic macro-invertebrates, fish, and phytoplankton are evaluated. The community structure and diversity, and distribution of benthic macro-invertebrates are related to sediment toxicity and thus they are mainly affected by in-place pollutants in the Harbor sediments. Pelagic fish and phytoplankton are mainly affected by pollutants in the water column and very little, if present, by the in-place pollutants in the sediments.

The ecological effects of in-place pollutants in Baltimore Harbor were evaluated. These pollutants are of considerable concern, but they cannot be fully corrected except with simultaneous prevention of further addition of domestic and industrial waste discharges.

TABLE E-10

WATER QUALITY AND FISH MORTALITY DATA OF THE THREE EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 10

Exp. no.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality % 24-hrs	48-hrs
1	0.1	5.40	5.5	4	8.3	7.2	0	0
1	87.04	6.43	93.47	43,500	5.0	4.5	100	100
1	52.28	5.92	58.20	28,000	4.75	6.5	100	100
1	31.07	5.15	36.22	18,400	4.8	6.5	100	100
1	18.20	6.10	24.30	9,100	4.65	6.5	100	100
1	16.35	5.96	11.6	--	5.0	6.35	100	100
2	10.64	5.64	16.28	6,900	5.2	6.4	80	100
2	9.62	5.26	15.88	5,800	5.75	5.7	70	100
3	8.94	5.81	14.75	6,500	4.8	6.6	50	70
3	7.18	5.72	12.90	5,250	4.9	6.5	40	60
3	5.43	5.43	10.86	4,250	5.8	6.6	10	20
2	6.91	5.31	12.22	4,350	6.02	6.6	0	0
2	5.05	4.82	9.87	3,300	6.5	6.6	0	0
3	3.99	5.83	7.82	3,500	6.6	6.6	0	0
3	3.28	5.74	9.02	2,650	7.0	6.5	0	0
2	2.36	4.64	7.00	1,500	7.1	6.5	0	0

TABLE E-11

WATER QUALITY AND FISH MORTALITY DATA OF THE TWO EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 8

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality % 24-hrs	48-hrs
7	34.78	7.02	41.80	29,000	4.8	6.8	100	100
7	23.65	7.22	30.47	25,000	5.2	7.4	20	50
7	16.70	7.16	23.86	16,750	5.3	7.4	20	30
7	15.27	7.03	22.30	15,000	5.3	7.4	0	10
6	12.20	7.31	19.51	9,250	5.9	7.5	0	0
6	10.57	6.94	17.51	8,500	5.6	7.1	0	0
6	8.80	6.79	15.59	7,200	5.8	7.7	0	0
6	7.96	7.02	14.98	6,750	5.8	7.6	0	0
6	7.56	6.89	14.45	6,450	6.0	7.6	0	0
6	0.08	6.92	7.00	2	8.2	7.9	0	0
7	0.01	6.55	6.56	2	8.1	7.5	0	0

TABLE E-12

WATER QUALITY AND FISH MORTALITY DATA OF THE TWO EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR BOTTOM SEDIMENT, STATION 7

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality %	
							24-hrs	48-hrs
11	117.69	5.54	123.23	66,000	5.9	0.7	100	100
11	86.37	6.71	93.08	64,500	5.3	6.3	90	80
11	74.14	6.70	82.84	58,000	5.3	5.4	50	80
11	61.96	7.58	69.54	55,000	5.5	5.6	30	50
10	61.50	6.05	67.54	45,500	6.1	5.6	10	30
10	48.54	6.27	54.81	37,500	5.7	5.9	0	0
10	41.92	6.59	48.51	32,500	5.7	6.0	0	0
10	26.32	6.47	32.79	23,500	5.7	6.6	0	0
10	15.41	6,40	21.81	15,000	5.9	6.6	0	0
11	7.39	6.20	13.59	5,800	6.8	7.0	0	0
10	0.08	6.82	6.90	2	7.4	6.2	0	0

TABLE E-13

WATER QUALITY AND FISH MORTALITY DATA OF TWO EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 6

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality %	
							24-hrs	48-hrs
9	71.26	6.73	77.99	50,500	5.0	5.1	100	100
9	58.93	7.18	66.11	44,000	5.0	5.3	100	100
9	47.08	6.99	54.07	35,000	5.1	6.2	100	100
9	34.91	6.97	41.88	28,500	5.2	6.2	90	100
12	31.34	6.95	38.29	28,500	5.5	7.5	70	90
12	27.38	6.89	34.27	25,500	5.7	7.3	60	80
12	21.05	6.95	28.00	18,000	5.4	6.2	30	30
12	20.39	7.21	27.60	19,000	5.9	7.4	20	40
12	17.74	6.87	24.61	16,000	5.9	7.4	0	0
9	0.08	6.82	6.90	2	7.4	6.2	0	0
12	0.05	7.05	7.10	3	7.5	7.3	0	0

TABLE E-14

WATER QUALITY AND FISH MORTALITY DATA OF THREE EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 5

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality %	
							24-hrs	48-hrs
14	3.36	7.46	10.82	3,000	4.2	6.5	100	100
14	3.10	7.42	10.52	2,750	4.2	6.5	100	100
15	2.34	6.87	9.21	2,700	3.8	6.5	100	100
15	2.21	6.87	9.08	2,400	4.7	6.6	100	100
15	1.44	6.87	8.31	1,800	5.0	6.5	100	100
15a	1.44	6.85	8.39	1,800	5.0	6.5	100	100
15	1.40	7.11	8.51	1,400	6.2	6.5	90	100
15a	1.13	6.87	8.00	-	6.2	6.5	100	100
15a	0.92	7.12	8.04	1,300	5.6	6.6	80	90
15a	0.77	6.76	7.63	1,100	6.4	6.5	50	70
14	0.48	7.02	7.80	590	6.9	6.75	0	0
15	0.38	7.26	7.64	465	6.5	6.6	0	0
15a	-0.08	7.20	7.12	6.5	7.5	6.6	0	0
14	0.09	6.37	6.49	3	7.5	6.5	0	0

TABLE E-15

WATER QUALITY AND FISH MORTALITY DATA OF TWO EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 9

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality %	
							24-hrs	48-hrs
8	33.79	9.02	42.81	19,000	9.0	5.6	20	30
5	16.95	8.00	24.95	8,300	8.9	7.5	0	0
5	15.02	8.03	23.09	7,450	8.9	7.7	0	0
4	14.32	7.00	21.32	6,900	9.3	8.3	20	50
4	13.09	6.90	19.92	5,850	9.3	8.2	10	70
5	11.46	7.70	19.16	5,400	8.9	7.7	0	10
5	11.09	7.58	18.67	4,450	9.3	7.8	0	10
4	10.99	6.85	17.85	5,250	9.3	8.4	10	20
5	8.77	7.44	16.21	4,400	8.9	8.9	0	0
4	8.60	6.50	15.10	4,350	9.3	8.2	20	30
4	7.01	6.76	13.77	3,550	9.2	8.2	10	20
5	0.10	6.61	6.72	3.7	8.2	9.2	0	0
4	0	6.54	6.54	2.5	8.2	8.3	0	0

TABLE E-16

WATER QUALITY AND FISH MORTALITY DATA OF AN EXPERIMENT OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 4

Exp. no.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality % 24 hrs.	Fish Mortality % 48 hrs.
18	8.09	5.65	13.74	9,000	5.2	6.9	100	100
18	4.93	7.21	12.05	4,300	5.7	7.1	60	90
18	3.74	6.91	10.70	3,200	6.0	7.1	20	50
18	2.68	7.33	10.00	2,300	6.3	7.0	0	0
18	2.08	7.01	8.59	1,800	6.75	7.0	0	0
18	0.81	7.02	7.83	565	7.2	7.0	0	0
16	-0.25	6.73	6.48	2.5	7.6	7.1	0	0

TABLE E-17

WATER QUALITY AND FISH MORTALITY DATA OF TWO EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 2

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality % 24 hrs.	48 hrs.
16	20.94	7.66	28.60	17,000	4.2	6.1	100	100
20	10.48	6.95	17.43	6,000	4.4	6.5	100	100
20	9.41	6.16	15.57	5,700	4.4	6.5	100	100
20	8.43	7.26	15.69	5,400	4.4	6.6	100	100
20	7.58	6.78	14.36	4,800	4.6	6.6	80	100
20	6.70	7.08	13.78	4,200	4.9	6.7	70	80
16	4.94	7.05	13.99	3,400	5.7	6.5	50	70
16	3.82	7.00	10.82	2,700	6.0	6.5	0	0
16	2.45	7.02	9.50	1,800	6.75	6.5	0	0
16	1.19	6.98	8.17	740	7.2	6.5	0	0
16	-0.26	6.51	6.25	3	7.5	6.6	0	0

TABLE E-18

WATER QUALITY AND FISH MORTALITY DATA OF THE THREE EXPERIMENTS OF MUMMICHOGS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 1

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality & 24-hrs	48-hrs
17	21.14	6.22	27.36	20,000	4.5	6.0	100	100
21	22.41	7.82	30.23	16,000	4.5	6.2	100	100
21	18.43	7.61	26.04	14,000	4.6	6.2	100	100
21	17.10	7.43	24.53	12,000	4.6	6.5	100	100
21	13.92	7.46	21.38	8,000	4.7	6.6	100	100
24	11.08	7.55	18.58	6,650	5.9	6.6	40	60
24	9.29	7.55	16.83	5,850	5.8	6.9	30	60
24	8.56	7.64	16.20	5.250	5.9	6.9	10	40
24	7.38	7.50	14.90	4,850	6.2	6.7	10	10
17	5.01	6.91	11.96	3,700	6.5	6.9	0	0
17	3.54	7.04	10.57	2,750	6.7	6.9	0	0
17	2.60	6.96	9.56	2,150	6.8	7.0	0	0
17	2.14	7.07	9.30	1,600	7.2	6.9	0	0
17	0.79	7.01	7.80	565	7.6	6.7	0	0
21	- 0.06	6.97	6.91	3	7.8	6.7	0	0

TABLE E-19

WATER QUALITY AND FISH MORTALITY DATA OF THE THREE EXPERIMENTS OF MUMMICHOGS EXPOSED TO FULLER'S EARTH SOLUTION

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Fish Mortality %	
							24-hrs	48-hrs
26	123.45	9.95	133.40	31,000	7.3	5.3	90	100
26	114.15	9.18	123.33	25,000	7.6	5.1	70	70
26	104.14	8.10	121.24	25,000	7.7	5.9	20	60
26	97.82	9.20	107.02	29,500	7.5	6.1	20	30
26	77.33	9.41	86.74	21,000	7.6	7.2	10	10
25	61.05	9.78	71.83	17,000	7.3	6.5	0	0
25	49.16	9.65	58.81	15,000	7.6	7.0	0	0
25	42.15	9.62	51.77	12,000	7.7	7.3	0	0
25	24.57	9.69	34.26	5,950	7.9	7.1	0	0
23	26.25	8.44	34.69	5,650	7.8	7.3	0	0
23	19.48	8.44	27.92	4,600	7.9	7.4	0	0
23	16.33	8.37	24.70	4,400	7.9	7.5	0	0
23	14.90	8.29	23.19	3,700	7.9	7.5	0	0
23	11.98	8.28	0.26	3,150	8.0	7.1	0	0
25	0.04	9.39	9,43	3	8.1	7.4	0	0
23	0	8.79	8.79	2	7.9	7.1	0	0
26	0.04	9.34	9.38	2	7.9	7.5	0	0

TABLE E-20

WATER QUALITY AND FISH MORTALITY DATA OF THE FOUR EXPERIMENTS ON SPOT EXPOSED TO FULLER'S EARTH SOLUTION

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids	Turbidity JTU	DO mg/l	pH	Fish Mortality % 24-hrs	Fish Mortality % 48-hrs
29	122.06	9.63	131.69	33,000	5.6	7.4	100	100
29	98.84	9.18	108.02	26,000	5.5	7.7	100	100
29	77.20	8.70	85.90	24,000	5.5	7.6	100	100
35	75.08	10.69	85.76	23,000	6.5	7.5	100	100
29	74.73	8.43	83.57	24,000	6.2	7.7	90	100
35	74.48	9.82	84.30	21,000	6.3	7.6	100	100
36	70.30	11.31	81.61	25,000	5.9	6.5	90	90
36	67.89	11.79	79.67	27,000	5.4	7.4	70	70
36	66.48	12.06	78.54	26,000	6.6	7.5	80	80
35	64.34	10.90	75.24	20,000	6.3	7.7	80	80
35	51.52	9.78	61.30	16,000	6.1	7.7	50	50
36	49.60	10.70	60.30	20,000	6.1	7.5	50	50
27	26.37	9,73	18.05	6,100	6.9	7.9	0	0
27	-0.01	9.29	9.28	2	7.2	8.1	0	0

TABLE E-21

WATER QUALITY AND FISH MORTALITY DATA OF THE TWO EXPERIMENTS ON SPOT EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 10

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	DO	pH	Fish Mortality %	
							24-hrs	48-hrs
30	17.30	8.66	25.97	12,500	6.6	5.3	100	100
30	15.75	8.56	23.78	9,000	6.7	4.9	100	100
32	10.30	8.24	18.54	6,200	7.2	5.6	90	100
30	8.74	8.71	18.45	6,000	6.9	5.2	30	60
32	6.67	7.67	14.33	4,800	7.4	5.6	0	10
30	6.38	8.61	14.97	3,975	6.8	5.9	0	0
30	2.71	8.60	11.31	1,375	7.2	7.4	0	0
32	6.30	7.59	13.90	4,500	6.7	5.9	0	0
32	4.11	7.84	11.95	3,350	7.2	6.5	0	0
32	-0.23	8.96	8.73	2	7.5	8.1	0	0

TABLE E-22

WATER QUALITY AND FISH MORTALITY DATA OF THE TWO EXPERIMENTS ON SPOT SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 8

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	DO	pH	Fish Mortality % 24-hrs.	Fish Mortality % 48-hrs
31	53.93	8.68	62.61	39,500	5.9	4.4	100	100
31	46.68	8.82	55.50	36,500	6.6	4.5	100	100
31	29.29	8.07	32.36	26,500	6.1	4.7	100	100
31	21.97	8.42	30.39	19,000	6.6	5.0	100	100
34	20.39	10.02	30.41	18,500	6.8	5.2	80	90
34	17.46	9.27	26.73	17,000	5.3	5.3	20	40
34	16.60	9.31	25.91	14,750	5.5	5.4	10	20
34	16.53	9.70	27.23	15,250	5.5	5.5	10	40
34	15.79	9.24	25.03	14,500	6.4	5.6	0	40
31	14.09	8.34	22.43	12,000	5.5	5.5	0	0
31	0.25	8.15	8.30	2	6.6	8.0	0	0

TABLE E-23

WATER QUALITY AND FISH MORTALITY DATA OF THE TWO EXPERIMENTS ON SPOT EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 7

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	DO	pH	Fish Mortality %	
							24-hrs	48-hrs
38	38.25	10.42	48.67	36,500	6.7	5.4	90	100
38	36.76	10.98	47.74	33,500	6.6	5.4	90	90
38	31.67	10.63	42.30	29,000	6.8	5.5	60	90
38	29.31	10.43	39.74	27,000	6.6	5.5	20	20
38	27.81	10.20	38.01	26,000	6.7	5.6	0	0
39	21.19	9.86	31.05	17,500	6.1	5.4	0	10
39	14.79	9.96	24.75	14,500	6.5	5.9	0	0
39	12.87	10.14	23.01	13,000	6.5	6.3	0	0
39	7.74	9.94	17.68	9,000	5.8	6.1	0	0

TABLE E-24

WATER QUALITY AND FISH MORTALITY DATA OF THE TWO EXPERIMENTS ON SPOT EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 6

Exp. No.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	DO	pH	Fish Mortality	
							24-hr.	48-hr.
40	36.10	10.95	47.05	26,000	5.6	5.1	100	100
40	31.46	10.62	42.08	25,000	6.1	5.2	100	100
39	28.57	9.89	38.46	25,000	6.0	5.3	80	90
40	27.66	10.43	38.09	24,000	6.6	5.2	60	70
40	24.69	10.44	35.13	21,500	6.5	5.4	50	50
39	21.19	9.86	31.05	17,500	6.1	5.4	0	10
39	14.79	9.96	24.75	14,500	6.5	5.9	0	0
39	12.87	10.14	23.01	13,000	6.5	6.3	0	0
39	7.74	9.94	17.68	9,000	6.1	5.8	0	0

TABLE E-25

WATER QUALITY AND FISH MORTALITY DATA OF THE EXPERIMENTS WITH SPOT SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 5

Expt. No.	Suspended Solids g/l	Dissolved Solids g/l	Total Solids g/l	Turbidity JTU	PH	DO	Fish Mortality %	
							24-hrs	48-hrs
43	2.13	11.28	13.41	1700	5.9	6.5	100	100
43	1.96	11.32	13.28	1500	5.7	6.6	100	100
43	1.66	11.12	12.78	1300	5.6	7.0	100	100
43	1.63	10.96	12.59	1275	5.7	7.1	100	100
43	1.43	11.00	12.43	975	5.7	7.5	100	100
45	1.02	22.06	12.08	780	5.9	6.1	100	100
45	0.99	11.04	12.03	1100	5.8	6.6	100	100
45	0.89	7.02	7.90	950	5.8	6.5	90	100
51	0.62	13.46	14.08	545	6.5	6.2	10	60
45	0.57	11.14	11.71	678	6.2	6.6	0	0

TABLE E-26

WATER QUALITY AND FISH MORTALITY DATA OF AN EXPERIMENT WITH SPOT SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 4

Expt. No.	Suspended Solids g/l	Dissolved Solids g/l	Total Solids g/l	Turbidity JTU	PH	DO mg/l	Fish Mortality %	
							24-hrs	48-hrs
52	10.04	11.18	21.22	7700	4.7	6.1	100	100
52	6.90	11.53	18.43	6100	4.8	6.2	100	100
52	6.41	11.47	17.88	5500	5.1	6.4	100	100
52	5.92	11.72	17.64	5250	5.7	6.0	10	10
52	4.05	12.13	16.18	4000	5.6	6.5	0	0

TABLE E-27

WATER QUALITY AND FISH MORTALITY DATA OF THREE EXPERIMENTS WITH SPOT SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 2

Expt. No.	Suspended Solids g/l	Dissolved Solids g/l	Total Solids g/l	Turbidity JTU	PH	DO	Fish Mortality % 24-hrs	Fish Mortality % 48 hrs
46	8.41	11.77	20.18	5300	5.4	6.5	100	100
46	7.47	11.59	19.06	5100	5.3	6.4	90	100
46	7.34	11.87	19.21	4900	5.5	6.5	80	100
46	6.01	11.39	17.40	4450	5.5	6.3	80	90
49	5.83	12.08	17.91	4650	6.0	6.6	60	90
49	5.61	11.77	17.38	4200	6.0	6.3	50	70
42	3.53	10.82	14.35	2550	6.6	6.9	0	0
42	2.38	10.48	12.86	1600	6.8	6.7	0	0
42	1.03	1.073	11.76	900	7.1	6.8	0	0

TABLE E-28

WATER QUALITY AND FISH MORTALITY DATA OF TWO EXPERIMENTS WITH SPOT SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 1

Expt. No.	Suspended Solids g/l	Dissolved Solids g/l	Total Solids g/l	Turbidity JTU	PH	DO	Fish Mortality % 24-hrs	48 hrs
47	13.66	10.49	24.15	8200	5.6	6.4	100	100
50	11.23	10.79	22.02	7350	6.0	6.8	100	100
50	9.77	11.41	21.18	6550	6.2	7.1	70	80
50	8.99	10.81	19.80	5800	6.5	6.9	30	30
47	7.91	9.42	17.40	5200	6.1	6.6	20	20
47	6.13	10.31	16.44	4200	6.9	6.9	10	20
50	6.28	11.09	17.37	4000	6.5	6.8	0	0
50	4.48	9.13	13.61	3700	6.9	7.1	0	0

TABLE E-29

WATER QUALITY AND CLAM MORTALITY DATA OF THE EXPERIMENTS WITH SOFT-SHELL CLAMS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 1

Expt. No.	Suspended Solids g/1	Dissolved Solids g/1	Total Solids g/1	Turbidity JTU	PH	DO	Clam Mortality % 24-hrs	48 hrs
62	129.51	15.59	145.10	67,000	4.3	3.4	30	50
62	106.27	14.88	121.15	57,000	4.3	6.1	10	40
59	39.09	13.17	52.26	29,000	5.0	7.1	0	20
62	33.32	13.81	47.13	27,000	4.9	7.5	10	30
59	16.04	13.28	29.32	13,500	6.4	7.1	0	0
62	0.14	12.50	12.64	2	7.5	6.3	0	0

TABLE E-30

WATER QUALITY AND CLAM MORTALITY DATA OF EXPERIMENTS WITH SOFT-SHELL CLAMS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 2

Expt. No.	Suspended Solids g/l	Dissolved Solids g/l	Total Solids g/l	Turbidity JTU	PH	DO	Clam Mortality %	
							24-hrs	48-hrs
58	49.49	13.15	62.64	34,000	4.6	6.5	50	100
57	49.20	12.36	61.56	32,000	4.3	5.2	50	90
58	48.25	13.12	61.37	31,000	4.8	6.5	30	80
57	47.33	12.28	59.61	30,750	4.4	5.8	40	90
58	34.11	12.12	46.23	25,000	5.0	6.4	30	100
58	17.00	12.07	29.07	13,000	5.3	6.8	10	50
58	-0.02	11.05	11.03	4	7.4	6.8	0	0

TABLE E-31

WATER QUALITY AND CLAM MORTALITY DATA OF EXPERIMENTS WITH SOFT-SHELL CLAMS SUBJECTED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 4

Expt. No.	Suspended Solids g/l	Dissolved Solids g/l	Total Solids g/l	Turbidity JTU	PH	DO	Clam Mortality %	
							24-hrs	48-hrs
60	39.40	12.50	51.90	35,000	3.9	6.6	10	50
61	38.06	13.50	51.56	34,000	4.8	6.1	40	40
60	37.87	12.13	50.00	35,000	3.8	6.2	10	40
60	23.69	11.79	35.48	21,500	4.9	6.8	10	50
61	22.21	12.45	34.66	20,500	5.2	7.0	0	30
62	0.14	12.50	12.64	2	7.5	6.3	0	0

TABLE E-32

WATER QUALITY AND CLAM MORTALITY DATA OF TWO EXPERIMENTS WITH SOFT-SHELL CLAMS EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 5

Exp. no.	Suspended solids g/1	Dissolved solids g/1	Total solids g/1	Turbidity JTU	pH	DO mg/1	Clam mortality(%)	
							24 hrs	48 hrs
70	66.86	20.82	87.68	54,000	3.5	4.8	80	90
70	45.09	18.25	63.38	35,000	3.6	6.3	60	80
70	30.15	15.96	46.11	27,000	3.8	7.5	50	100
63	22.13	14.39	36.52	20,000	4.2	5.7	40	80
70	19.85	14.61	34.46	17,500	3.5	7.4	40	90
63	10.74	12.47	23.21	10,000	3.7	6.3	30	80
70	8.72	13.01	21.73	6,050	4.5	7.7	20	90
63	0.10	11.42	11.52	3	7.5	8.0	0	0
70	0.06	12.14	12.20	3	7.8	7.5	0	0

TABLE E-33

WATER QUALITY AND CLAM MORTALITY DATA OF TWO EXPERIMENTS WITH SOFT-SHELL CLAMS EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 6

Exp. no.	Suspended solids g/l	Dissolved solids g/l	Total solids g/l	Turbidity JTU	pH	DO mg/l	Clam mortality (%)			
							24 hrs	48 hrs	72 hrs	96 hrs
74	150.75	13.53	164.28	91,000	4.2	6.4	0	40	60	100
67	139.77	11.61	151.38	100,000	4.3	6.6	0	10	20	100
74	135.41	12.95	148.36	95.500	4.4	6.8	0	40	80	100
67	131.94	11.40	143.34	87,000	4.3	7.8	0	0	10	100
67	130.05	11.33	141.38	81,000	4.3	5.1	0	0	20	100
67	- 0.07	12.39	12.32	2	7.6	7.4	0	0	0	0

TABLE E-34

WATER QUALITY AND CLAM MORTALITY DATA OF TWO EXPERIMENTS WITH SOFT-SHELL CLAMS EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 7

Exp. no.	Suspended solids g/1	Dissolved solids g/1	Total solids g/1	Turbidity JTU	pH	DO mg/1	Clam mortality (%)			
							24 hrs	48 hrs	72 hrs	96 hrs
77	173.21	13.97	187.18	175,000	4.7	6.6	0	30	100	100
77	167.21	13.14	180.35	150,000	4.8	6.5	0	60	100	100
85	147.26	14.67	161.93	150,000	4.9	6.5	0	30	100	100
72	137.71	11.69	149.40	98,500	4.7	6.1	0	20	50	100
85	121.75	16.58	138.33	94,000	4.8	6.6	0	0	50	100
68	108.82	10.86	119.28	77,000	4.8	7.2	0	0	20	60
85	103.61	12.79	106.40	75,000	4.9	6.3	0	0	10	60
77	0.06	12.14	12.20	3	7.8	7.5	0	0	0	0

TABLE E-35

WATER QUALITY AND CLAM MORTALITY DATA OF TWO EXPERIMENTS WITH SOFT-SHELL CLAMS EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 8

Exp. no.	Suspended solids g/1	Dissolved solids g/1	Total solids g/1	Turbidity JTU	pH	DO mg/1	Clam mortality (%)			
							24 hrs	48 hrs	72 hrs	96 hrs
76	113.80	13.34	127.14	85,000	4.7	6.8	10	60	100	100
76	101.98	13.23	115.21	73,000	4.4	6.2	20	40	90	100
76	96.15	13.09	109.24	70,000	4.5	6.4	0	20	70	100
69	84.39	10.88	95.27	68,000	4.5	6.5	0	0	0	20
69	68.42	8.64	77.06	52,500	4.7	6.7	0	0	0	40
76	0.06	12.14	12.21	3	7.8	7.5	0	0	0	0

TABLE E-36

WATER QUALITY AND CLAM MORTALITY DATA OF TWO EXPERIMENTS WITH SOFT-SHELL CLAMS EXPOSED TO THE SOLUTION OF BALTIMORE HARBOR SEDIMENT, STATION 10

Exp. no.	Suspended dolids g/1	Dissolved solids g/1	Total solids g/1	Turbidity JTU	pH	DO mg/1	Clam mortality (%)		
							24 hrs	48 hrs	72 hrs
80	156.48	14.28	170.76	97,000	3.8	6.0	40	80	100
80	152.39	16.03	168.42	81,000	3.8	5.8	20	90	100
81	150.87	15.66	166.53	83,000	3.8	5.6	30	90	100
81	144.91	14.48	159.39	83,500	3.8	5.7	30	70	90
81	132.39	13.87	146.26	75,000	3.9	5.4	0	60	100
81	0.25	13.34	13.59	2	7.4	7.7	0	0	0

TABLE E-37

WATER QUALITY AND CLAM MORTALITY DATA OF THREE EXPERIMENTS WITH SOFT-SHELL CLAMS EXPOSED TO SOLUTION OF FULLER'S EARTH

Exp. no.	Suspended solids g/1	Dissolved solids g/1	Total solids g/1	Turbidity JTU	pH	DO mg/1	Clam mortality (%)			
							24 hrs	48 hrs	72 hrs	96 hrs
78	202,07	10.32	212.39	53,000	7.2	3.8	0	10	40	90
86	176.43	11.76	188.19	44,000	7.3	2.0	0	20	30	40
78	144.55	10.23	154.78	36,000	7.3	5.1	0	0	30	90
83	127.85	12.21	140.06	38,500	6.4	6.3	0	0	20	60
83	124.61	12.09	136.70	41,000	7.2	6.0	0	0	10	20
78	119.09	10.28	129.37	28,250	7.4	7.4	0	0	20	90
78	78.68	10.17	88.85	22.250	7.5	7.0	0	0	0	10
86	66.99	11.21	78.20	23.500	7.4	5.3	0	0	0	20
86	0.02	11.19	11.21	2	7.3	8.0	0	0	0	0

APPENDIX F

SUPPLEMENTARY DATA ON DREDGING, DISPOSAL, AND BLANKETING TECHNIQUES

F.1 DREDGING AND DISPOSAL

One of the more important recent investigations of the effects of dredging in an estuarine environment is a detailed study of the effects of dredging and disposal in the San Francisco Bay and Estuary by the U. S. Army Corps of Engineers. This study, as reported in July 1975, reached a number of conclusions. Those which are most important to an understanding and consideration of dredging and spoil disposal results of the San Francisco study final composite environmental statement are quoted below:

> "The purpose of this Statement of Findings is to set forth the rationale leading to a recommendation that the maintenance dredging for the Federal navigation projects in San Francisco Bay be continued as authorized, and as described in the Final Composite Environmental Statement".
>
> "3. Rationale and Discussion. The possible consequences of the navigation projects have been studied for environmental, social well-being, economic effects (including regional and national economic development) and engineering feasibility. In evaluating the projects, the following points were considered pertinent:
>
> a. Environmental Considerations.
>
> (1) Bay Estuary - Turbidity in the upper water column from a dredging activity usually lasts less than 15 minutes with the highest turbidity values adjacent to the dredge. In addition to the turbidity plume created in the upper water column, dredging induces an ill-defined fluff zone in the channel bottom which can last up to several weeks. This fluff zone shifts with the tide but is localized to the channel boundaries, and eventually consolidates.

"Material released at open water disposal sites reaches the bottom relatively intact. Less than five percent of the material is dispersed in the upper water as the material descends. The disposed sediments are subsequently dispersed within the bottom few feet of the water column, diluted, and follow the circulation pattern of natural sediment distribution in the Bay.

Benthic organisms experience various amounts of dredging impact depending on the surface area distributed, the numbers and species present, depth of the cut, and frequency of maintenance. In San Francisco Bay, it does not appear that sediments from disposal operations cause extensive smothering of benthic organisms because the disposal areas are high energy areas where currents are swift and continuous. Estuarine fish (including anadromous fish) are generally tolerant of relatively high turbidity and can avoid or move away from immediate areas of impact.

Dredging and disposal have adverse impacts on bottom dwelling organisms in the immediate work areas. Some organisms are destroyed at both the dredging and disposal site, while others are transported to the disposal site. Indications are that, while there is some diversity of life at project and disposal sites, these areas, in general, do not have as great an abundance of life as those areas outside the channel or disposal sites.

To date, there is no indication that dredge and disposal operations directly influence uptake of toxic constituents although there is evidence of limited release of some contaminants during sediment agitation.

b. Social Well-Being Considerations.

(1) Historical and Archaeological Sites - All 20 projects are areas previously dredged. Of the five projects involving land disposal, only the Port of Redwood City has tentatively chosen a land disposal site. The site has been investigated by an archaeologist and the determination has been made that no archaeological resources exist and that no historical sites will be affected. Any other potential sites for Port of Redwood City land disposal and

"land disposal sites for other projects will be surveyed by a professional archaeologist, and a supplement to the environmental statement will be issued to cover this and other considerations.

(2) Demography and Land Use - Most of the 20,400 port-related jobs are in core urban areas and help sustain the economic health of those areas. Maintenance dredging is essential to port operations; thus it strengthens the inner city economies and to some extent retards the exodus from cities to suburbs.

(3) Government - Port activities comprise a vital part of socio-economic structures of city government land use plans.

(4) Transportation - Trucking and rail lines interface with waterborne commerce in the Bay area to link water and land freight transfer. Maintenance dredging serves to continue this efficient and economical land-water freight system.

(5) Recreation - Maintenance dredging benefits some recreational boaters in areas such as San Rafael Creek and San Leandro Marina as well as all other marinas covered under Corps permit program. Cessation of maintenance dredging would have a negative social impact on such recreation activities.

(6) Scenic Resources - Land disposal would have an aesthetic impact. If land disposal is utilized, this impact will be assessed in the appropriate supplemental environmental statement.

c. Engineering Considerations.

(1) Existing Project - The Federal navigation projects under consideration have already been constructed. Hydrographic surveys are routinely done to determine when maintenance dredging is required and to estimate the amount of material to be dredged.

(2) Land Disposal - Those projects for which land disposal is being considered will be subjected to engineering review and analysis. This review and analysis will consider such items as seismic hazards, ground water, runoff, etc. Supplemental environmental statements for these projects will include these considerations.

"(3) Future Projects - New dredging projects, both Federal and private requiring a permit, and expansion of current projects will be the subject of engineering review and analysis and will have separate environmental reports issued on them.

d. Economic Considerations.

(1) Economy - Maintenance of Federal navigation projects will have a positive impact on the San Francisco Bay regional economy. Dredging is considered to have beneficial long-term impacts for maintaining port facilities and navigation commerce, helping to maintain land values, public revenues, and the provision of community services. Total military and civil port investment in the Bay-Delta area was nearly $2 billion through 1973. Over 4,500 vessel trips with ships greater than 25-foot draft, requiring dredged channels for navigation, passed through San Francisco Bay and over 56 million tons of cargo were handled in Bay-Delta ports in 1973.

(2) Employment - the Federal navigation projects maintain channels that serve commercial ports, private wharves, oil piers, and military installations that are dependent on Bay access. Approximately 7,800 jobs were related to export in the Bay area. Numerous other jobs are indirectly related to waterborne transportation.

e. Alternative Considerations.

(1) No Maintenance - In order to provide open navigation channels for commercial shipping and other purposes in the national interest, dredging in the Bay area has become a continual operation and it is doubtful that maintenance dredging would be permanently halted. Two programs of decreasing maintenance dredging activities, partial and complete moratoriums, would be extreme measures having severe negative socio-economic impacts throughout the Bay region and the nation, as well as both positive and negative environmental effects.

(2) Alternate Dredging Methods - Present dredging methods in the Bay include the hydraulic cutterhead pipeline, the hopper dredge and the clamshell dredge. Each method is uniquely suited for particular project conditions. Studies are being conducted to develop methods which may reduce impacts on the aquatic environment without decreasing dredging efficiency. All methods are required to meet the total dredging requirement.

"(3) Alternate Disposal Sites - Alternative proposals for disposal in the Bay are ocean disposal, land disposal, and salt marsh development. Large scale ocean disposal by hopper and/or barge is uneconomical and not in line with energy conservation. A conceptual plan of a permanent, self-contained pipeline system to the ocean disposal site was investigated for economic feasibility, but appears infeasible in the short run. Any ocean disposal plan would require a detailed study in which alternative ocean disposal plans would be thoroughly assessed prior to approval. Land disposal is a short-term alternative and should be considered as an alternative to aquatic disposal. Should land disposal be selected for a particular project, a supplemental environmental statement will be prepared covering all aspects of this alternative. Marsh development studies have shown this to be a feasible alternative; however, like other land disposal alternatives, it should be considered short-term and of limited applicability.

(4) Economic Consideration for Alternatives - Economic analysis of the cost efficiency of alternative dredging and disposal systems were derived in the following ranking (from least expensive to most expensive): closest aquatic disposal (no constraints on disposal), closest aquatic disposal seaward of the dredge site (no constraints), ocean disposal (100-fathom contour), land disposal (Petaluma River Area), delta island reclamation (Sherman Island), and marshland development (Petaluma River Area).

(5) Reduce Shoaling Rate - Studies have been conducted involving structural plans to either prevent shoaling in the navigation channels or to increase flushing of the channels, and selection of alternative aquatic disposal sites to reduce the amount of sediments returning to the channels.

(6) Development in Dredging Technology - Important factors being considered involve improving the efficiency of dredging techniques, acquiring new equipment, applying chemical additives, and adjusting the timing, scheduling, and methodology of dredging operations. These factors are being studied by the Corps.

f. Other Public Interest Considerations.

(1) Federal Navigation Projects - Federal navigation projects planned for the coming year are announced in a single public notice. Revised public notices are issued as required.

" (2) Regulatory Permit Actions - Dredging projects for which a Department of the Army permit is required are announced by public notice. For small volumes (less than 10,000 cubic yards) involving land disposal above MHHW, no public notice is issued; however, all concerned agencies are afforded the opportunity to comment on the project.

(3) Public Hearings - If requested, public hearings are held on both Federal navigation projects and permit dredging projects. These hearings afford concerned agencies and individuals additional opportunity to comment.

4. Conclusions and Recommendations. Based on an analysis and evaluation of the investigation conducted on the proposed Federal navigation projects, I find that an interdisciplinary approach has been used in the preparation of the Final Composite Environmental Statement and that all major environmental issues have been addressed. I find that where the proposed projects have adverse environmental effects, these effects are limited (based on available study results), or are substantially outweighed by other positive considerations. There are no adverse economic effects with regard to these projects. On the contrary, there are substantial positive economic benefits to be gained by the Bay Area, and a curtailment of these maintenance projects could, in fact, have a major adverse economic impact.

Therefore, based on a thorough analysis, and evaluation, I recommend that the subject Federal navigation projects be maintained as authorized, with the understanding that land disposal will be analyzed in supplements. I further recommend that the Final Composite Environmental Statement be used to aid in assessing the impacts of future permit navigation projects. I find this recommendation consistent with national policies, statutes, and administration directives.

/s/ H. A. Flertzheim
28 November 1975
H. A. FLERTZHEIM, JR.
Colonel, CE
District Engineer "

F.1.1 Pneuma® Dredge

The Pneuma® Dredge is a dredging and transport system which has been developed by Pneuma® International S.A., an Italian firm. The dredge design uses compressed air for pumping and uses hydrostatic pressure to remove materials from the bottom. The system has been used in most standard dredging applications and has achieved acceptance, particularly in stiuations involving the removal of sediments from channels and harbor areas. It is claimed that very little sedimentation is caused by the cutting and removal actions of the system. High percentages (60 - 90%) of solids are also reported.

The system uses three cylinders grouped together to form a pump body. Special valves for inlet and outlet are installed on each of the three cylinders. A distributor functions to automatically control the supply of compressed air to each cylinder and the exhaust of compressed air from the cylinder to the atmosphere. When the pump body is submerged, water fills the pump body after lifting the inlet valve in each cylinder due to the hydrostatic head. The water, or the material to be dredged, enters the pump body through an inlet tube which extends below the pump body and to which may be attached various suitably shaped shovels. When the pump body has been filled, the distributor supplies compressed air to the pump body. The inlet valve closes because the pressure inside the pump body is now greater than the ambient hydrostatic pressure; and the air pressure acts as a piston, forcing the material inside the pump body out through a pipe which extends to the lower portion of the pump body. When the cylinder has been almost emptied, the distributor vents the air in the cylinder to the atmosphere and equalizes the cylinder internal pressure with atmospheric. This naturally creates a pressure differential between the inside of the cylinder and the hydrostatic pressure. This pressure differential induces the flow of sedimentary materials through the inlet tube, lifting the inlet valve and refilling the cylinder. In order to maintain a continuous flow rate, the distributor acts on the three cylinders in turn, repeating the cycle described above.

Since there is little mechanical disturbance of the bottom sediments from the action of the Pneuma® Dredge, very little turbidity is produced.

This descriptive material was extracted from a "Test Report on Dredging by S.I.R.S.I. Pneuma® Pump System", from the abstracts of "The Japan Dredger Technical Society", Number 82, July 1972, by Y. Takamura, S. Kasajima and C. Mukai, all of the Port and Harbor Bureau, City of Osaka.

F.2 BLANKETING

Blanketing is a technique that has been used to control the turbidity caused by the disturbance of sea-floor sediments. In some underwater work, the reduction to visibility which may persist for some hours after disturbance is a serious hindrance to continued work by divers. In order to deal with this problem, local applications of plastic sheeting, the pouring of hydraulic mortar and the formation on an in-place plastic film have been explored. For one of the purposes of this study, the evaluation of possible remedial actions to reduce or eliminate the impact of pollutants upon the Harbor waters, it appeared valuable to pursue the possibilities of a formed-in-place plastic layer. Successful placement of a plastic layer could offer two advantages: (1) preventing the disturbance of contaminated sediments and (2) isolation of the water column from the in-place contaminated sediments.

A description of a process to form such a plastic film in place on the sea bottom is contained in Technical Note N-1107, "Chemical Overlays for Seafloor Sediments", by T. Roe, J. S. Williams and H. J. Migliore, June, 1970, published by the Naval Civil Engineering Laboratory, Port Hueneme, California. This Technical Note and United States patent number 3,845,003, granted to Thorndyke Roe, Jr., and assigned to United

States of America as represented by the Secretary of Navy, provide the basis for the information which follows.

The Technical Note and the patent describe the use of the following two distinct film-forming chemical solutions, each of which precipitate when extruded through a slit into sea water:

		Parts by Weight
1.	Polyvinyl butyral resin	1.0
	2-(2-ethoxyethoxy) ethanol	28.4
	Citric acid	13.4
	Dibutyl Phthalate	7.9
	Dimethyldicocoammonium chloride 75% active	0.1
2.	Polyvinyl butyral resin	1.0
	2-(2-ethoxyethoxy) ethanol	24.6
	Chlorinated Paraffins	12.0
	Dibutyl Phthalate	6.0
	Dimethyldicocoammonium chloride, 75% active	2.1

In practice, these solutions have been found to provide a continuous flexible non-toxic plastic film capable of covering the ocean floor sediment and preventing the sediment from becoming disturbed and suspended in the sea water. Also, these non-toxic plastic films were found to have a strength sufficient to support light loads and a strength which increased with deposit time.

Included in the solution is an antistatic agent to reduce the static electricity on the extruded plastic film. This enhances the spreading of the plastic film by allowing the film to spread in thinner sheets than would otherwise be possible. The antistatic agent utilized in the present invention is Dimethyldicocoammonium chloride, 75% active.

The other significant factor in the formulation is the use of a solvent which itself is miscible and preferably soluble in sea water. Consequently, when the solution initially is exposed to the sea water, the solvent commences to dissolve in the sea water permitting the resin system to precipitate out in a desired manner. The initial film formed by the precipitation is sufficiently cohesive to provide a continuous sheet although the toughness or strength of the sheet will not be achieved until the solvent has completely dissolved in the water.

In the same period (1967-69) under contract to the Supervisor of Salvage, U. S. Navy, Battelle Memorial Institute developed a two-component overlay method in which sodium alginate containing titanium dioxide as a weighing agent is insolubilized by treatment with dilute hydrochloric acid. The overlay formed instantly and had fair mechanical properties. Its surface was quite slippery; and when walked upon, it tended to extrude or creep out from under one's feet and break up. It had some resilience and very low tensile strength. If a large area is to be covered, adjacent layers of this material cannot be bonded to one another, but must be overlapped or cross-hatched. Because of its requirement for two components, its marginal mechanical properties and its inability to bond to itself, this method is not recommended for future development.

Pilot-test costs for these overlays were on the order of $1.00 per square foot (1970).

Experimental runs of fixed-slit dispensers with candidate overlay solutions were conducted in 25 feet of water off Santa Cruz Island and in 50 feet of water off Anacapa Island. These tests indicated that a chemical overlay dispensing system could not be entirely diver-operated. Any system which requires divers to swim above the sediment with a dispenser and attached hose was found to be impractical because the dispenser and hose are too cumbersome to be handled in this manner. For this reason, two dispensing system prototypes were proposed: one to be used on a Construction Assistance Vehicle (CAV), and a subsequent model to be used on a deep-water submersible.

The CAV provides a load bed that can support a dispensing-system prototype. As the CAV cruises over an intended work site, the dispenser, suspended from the stern, can apply chemical overlay solution on the sea floor. Several parallel runs, overlapped at the edges, would completely cover the site. With the CAV in mind, the main features of the chemical overlay dispensing system include: (1) 600-gallon capacity; (2) at least 100 square feet per minute and 2000 square feet per hour coverage; (3) storage container to be pressure-compensated; and (4) stipulations to ensure convenience and efficiency in operator control.

F.3 APPENDIX F - REFERENCES

-- U. S. Army Corps of Engineers, Final Composite Environmental Statement, Maintenance Dredging, Existing Navigation Projects, San Francisco Bay Region California, Volume 1, December 1975. (Quoted in section F. 1)

APPENDIX A - Main Ship Channel (San Francisco Bar)
Study of the effects of dredging and disposal on the Bar outside of the Golden Gate and consideration of optimal procedures.

APPENDIX B - Pollutant Distribution
Not yet available.

APPENDIX C - Water Column
Observations in the Bay of the effects of dredging and spoil placement, with special attention to oxygen demand, suspended solids, mounding or dispersal of deposits and the factors affecting these characteristics.

APPENDIX D - Biological Community
Detailed survey of the distribution and abundance of infauna at 11 stations in San Francisco Bay and analysis of the heavy metal content of the biota and of some environmental conditions.

APPENDIX E - Material Release
Not yet available.

APPENDIX F - Cyrstalline Matrix
Sediments from nine sites were analyzed for physical, chemical, and mineralogical parameters and the data were analyzed with reference to implications for dredge-related activities. Many components and conditions were included.

APPENDIX G - Physical Impact
Experimental evaluation of the effects of fine sediments in suspension and of cataclysmic deposition on estuarine macrofauna, with interpretation in redredging activities. Experiments involved effect of sediments, temperature,. of depressed oxygen concentrations

and of simultaneous variation of all three. Includes the edible mussel, young striped bass, a perch, sand shrimp, and others. Good literature review.

APPENDIX H - Pollutant Uptake
Report on field experiments in which resident and transplanted organisms were observed before, during, and after near-by dredging activity for heavy metal uptake and effects.

APPENDIX I - Pollutant Availability
Results of an experimental placement of polluted sediments and detailed observations on resident and transplanted benthic species.

APPENDIX J - Land Disposal
Analysis of the economic, technical, and environmental aspects of land placement of materials dredged from San Francisco Bay.

APPENDIX K - Marsh Development
Report on experimental efforts to create suitable habitat for marsh development and encourage development of California cord grass, Spartina foliosa, and pickleweed, Salicornia sp. Methods, costs, and pollutants for San Francisco Bay are presented.

APPENDIX L - Dredging Technology
Field observations and tank simulation of release patterns of various types of sediment were analyzed to assist in predicting the mounding or spreading and other attributes of the release pattern.

-- Biological Impacts of Suspensions of Dredged Material, Richard Peddicord, U. S. Army Corps of Engineers, Waterways Experiment Stations, Environmental Effects Laboratory, Vicksburg, Mississippi, Paper presented at WODSON VII, World Dredging Conference, San Francisco, California, July 10-12, 1976.

-- Effects of Suspended Solids on San Francisco Bay Organisms, R. Peddicord, V. A. McFarland, D. P. Belfiori, T. E. Byrd, University of California, Bodega Marine Laboratory, Bodega Bay, California. Paper presented at WODCON VII, World Dredging Conference, San Francisco, California, July 10-12, 1976.

-- Applications of Predictive Sediment Transport Models, by R. B. Krone, University of California, Davis, California, and C. R. Ariathurai, Nielson Engineering and Research, Inc., Mountain View, California.

-- Containment Area Facility Concepts for Dredged Material Separation, Drying and Handling, by C. W. Mallory and M. A. Nawrocki of Hittman Associates, Inc., for the Dredged Material Research Program of the Environmental Effects Laboratory of the U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

-- Identification of Relevant Criteria and Survey of Potential Application Sites for Artificial Habitat Creation, Volume 1, Relevant Criteria for March-Island Site Selection and Their Application, by Coastal Zone Resources Corporation, Wilmington, North Carolina, October 1975.

-- An Examination of some Physical and Biological Impacts of Dredging in Estuaries, Interdisciplinary Studies of the Schools of Engineering and Oceanography, Oregon State University, Corvallis, Oregon submitted to the Division of Environmental Systems and Resources (RANN), National Science Foundation, Washington, D.C., NSF RANN GRANT GI 34346, December, 1974.

APPENDIX G

BIBLIOGRAPHY

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American Public Health Association. Standard methods for the examination of water and wastewater. 13th Edition. 874 p. 1971.

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APPENDIX H

ACKNOWLEDGEMENTS AND PARTICIPANTS

H. 1 CONTRACT AND CONTRACTORS

This project was undertaken for the Environmental Protection Agency, Toxic Substances Branch, 401 M Street, WSM, Washington, D. C. 20460, under Contract No. WA 75 - R263.

Contractor for the project was Trident Engineering Associates, Inc., 48 Maryland Avenue, Annapolis, Maryland 21401, in conjunction with the Center for Environmental and Estuarine Studies, University of Maryland, Horn Point, Cambridge, Maryland 21613.

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The firm WAPORA, Inc., 6900 Wisconsin Avenue, Washington, D. C., performed the chemical analysis for all parameters of the sediment samples, filtered water, interstitial water, and the elutriate analysis.

The firm Analytical Bio Chemistry Laboratories, Inc. (ABC), Columbia, Missouri, performed the PCB analysis of the sediment samples.

The firm Micromeritics, Norcross, Georgia, Performed the particle size and surface area analysis of the sediment samples.